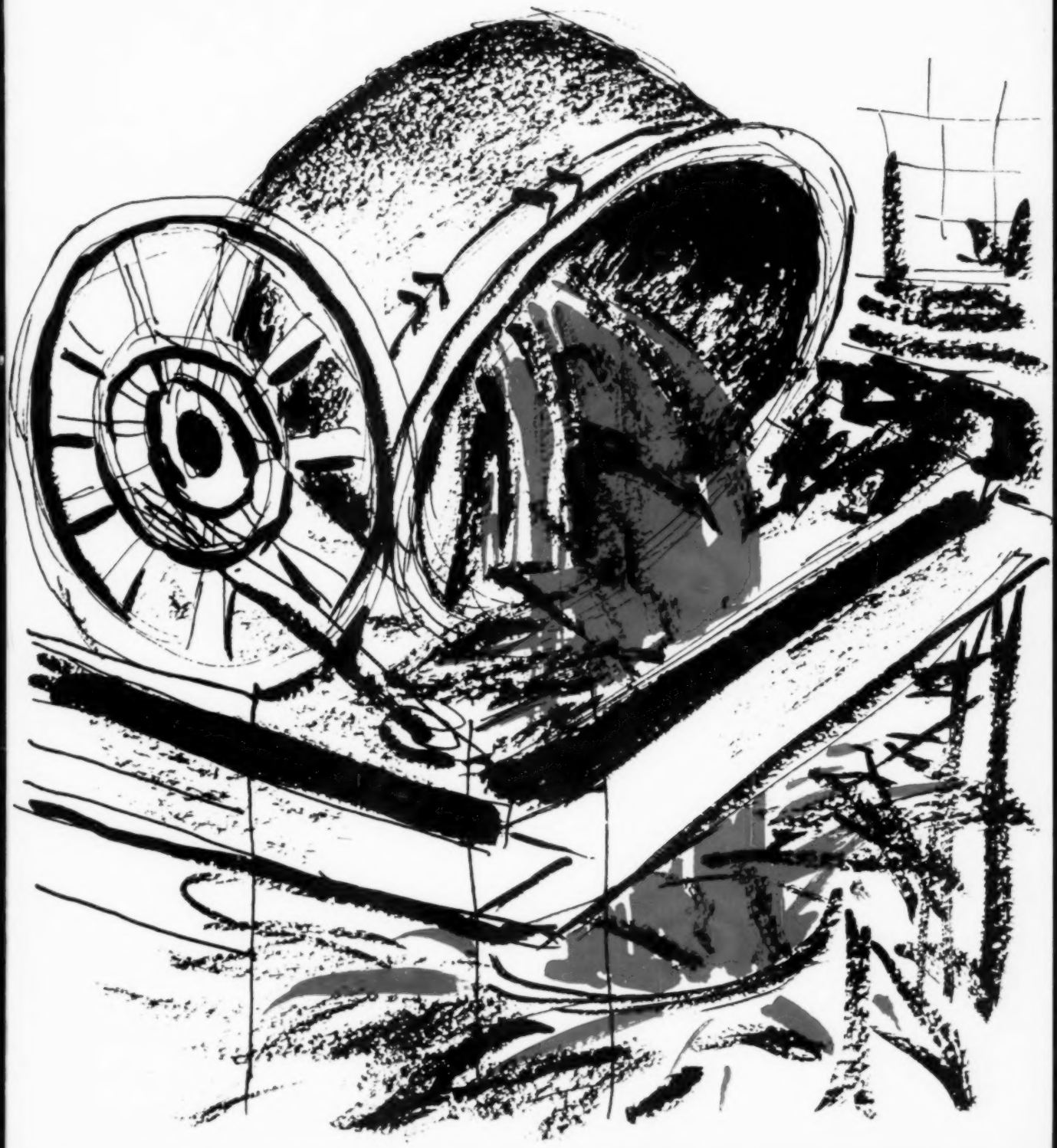
JOURNAL OF

METALS

MAY 1959



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JOURNAL OF

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COVER:

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PERSONNEL

► These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the national societies of Civil, Electrical, Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 5% of the first year's salary if a non-member, or 4% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately, by our office, after receiving your application. In sending applications be sure to list the key and job number.

When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

A weekly bulletin of engineering positions open is available at a subscription rate of $3.50 per quarter or $12 per annum for members, $4.50 per quarter or $14 per annum for non-members, payable in advance. Local officers of the Personnel Service are at 8 W. 40th St., *New York 18;* 57 Post St., *San Francisco;* 84 E. Randolph St., *Chicago 1.*

— MEN AVAILABLE —

Metallurgical Engineers, B.Sc. and M.Sc., metallurgical engineering, age 29, married, family. Seven years research and development work with company designing and manufacturing aircraft gas turbines. Three years supervisory position in metallurgical development of materials used in gas turbines. Desires responsible position metallurgical research or development. M-212

Metallurgist, B.S.Ch.E (major in met.), age 33. Seven years experience physical and mechanical metallurgy related to development and processing of diversified non-ferrous alloys. Experience with alloy steels and use of tool steels. Supervision. Desires responsible position with progressive concern. Qualified for production, development, or technical sales. Prefer Detroit area. M-938-Chicago.

Metallurgist, ore dressing, extractive-mineral, age 53. Chemical, 5 years; consulting metallurgist, mining companies, Latin America, 4 years; chief metallurgist, mill designer, Pb-Zn-Cu mine, 7½ years; metallurgist, laboratory of government, trouble shooter, superintendent of plants, mines in South America, 3 years; Jr. Analyst, 1 year; assayer, chemist, charge of laboratory. Location, immaterial. M-1183-San Francisco.

— POSITIONS OPEN —

Manager, product and engineering development for metal research laboratory concerned with various phases of research and development in aluminum and brass operations. Will be in charge of engineering development and product development work. Require engineer with knowledge of engineering in general. High salary. Location, Connecticut. W7253.

Sales Engineer with engineering training and field sales experience selling non-ferrous ingots, castings, brass and bronze alloys, etc. Salary, $7000 to 8000 year. Territory, Maryland, Pennsylvania, New Jersey. Headquarters, New Jersey. W7194.

Metallurgists and Chemists. a) Physical metallurgist to work on casting, fabrication, and the heat treatment of experimental alloys in a non-ferrous research laboratory, or to work on metallurgical problems associated with X-ray flouresecence analysis, in which case some experience in that field would be highly desirable; or assignment might be in making elevated temperature tensile tests with eventual work in fatigue, creep and stress rupture. Salary open. b) Mechanical metallurgists, M.S. degree, perhaps a Ph.D, with minimum of five years experience in tensile, fatigue, creep and stress rupture testing (including elevated temperature work), with some supervisory experience. Salary open. c) Research chemist, advanced degree in analytical chemistry, with minimum of five years experience in non-ferrous metallurgical analysis. Experience in gas analysis of metals in desirable but not essential. Salary open. Location, New England. W7193.

(Continued on page 298)

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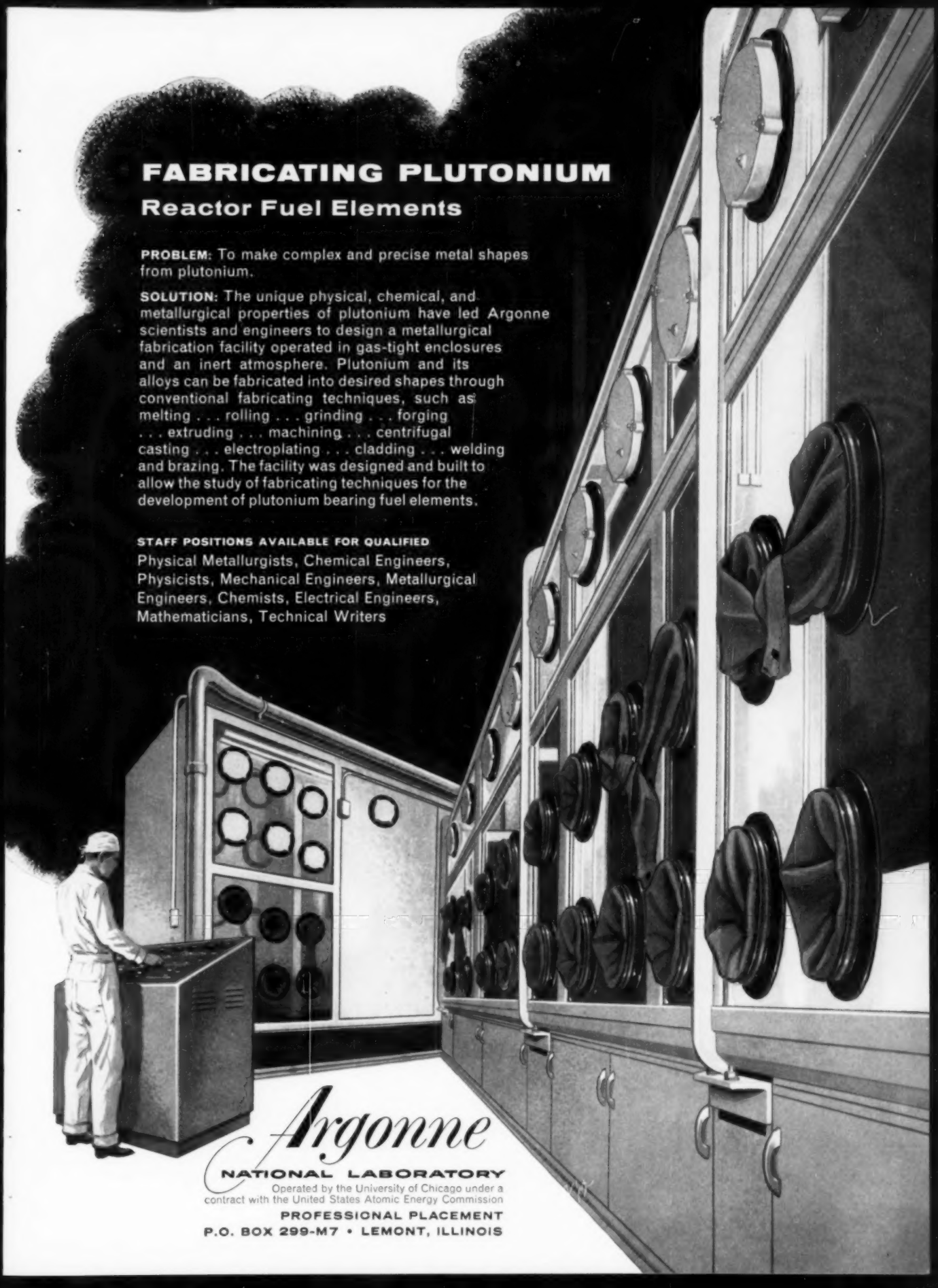

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Personnel

(Continued from page 296)

Metallurgists, 2, graduates, to take over quality control in large iron and steel foundry. Salaries, $10,000 to 12,000 year. Company will pay placement fee and probably relocation expenses. Locations: southern Illinois and western Pennsylvania. W7190.

Industrial Engineer, graduate mechanical or I.E., to organize and administer an incentive standard wage plan in a large foundry and machine plant in the non-ferrous metal field. Salary open. Location, Massachusetts. W7189.

Process Metallurgist, non-ferrous, Ph.D or equivalent in physical metallurgy, with experience in copper and/or aluminum alloys. Two to four years experience in melting and casting required. Continuous casting experience desirable. Position with research laboratory. Salary, $7300 to 11,000 year. Location, New England. W7188-S4169.

Physical Metallurgist, non-ferrous laboratory; Ph.D or equivalent, with two years research and development experience in physical metallurgy of copper and aluminum base alloys. Alloy development experience desirable. Position with research laboratory. Salary, $7000 to 10,000 year. Location, New England. W7187-S4170.

Metal Surface Research Engineers, non-ferrous metal. a) Recent Ph.D, physics or electro-chemistry, familiar with fused salt chemistry. Good experimentalist with interest in mechanism of fused salt-metal oxide reactions. b) Recent Ph.D or equivalent in physical-surface chemistry. Research problems associated with surface reactions and oxide films. c) Project engineer, Ph.D or equivalent in chemical metallurgy or surface physics. Three or more years experience corrosion research with emphasis on metallurgical aspects. Responsible for major non-ferrous corrosion research projects. Salaries, $7000 to 10,000 year. Location, New England. W7186-S4168.

Ferrous Metallurgist, B.S. in metallurgy or mining, M.S. or M.B.A. would be desirable. Eight to fifteen years experience in raw materials used by the steel industry, with particular emphasis on utilization of iron ores and iron products. Should have detailed knowledge of sponge iron techniques or comparable methods of upgrading natural iron ores for direct use in open-hearth or electric furnaces; ability to make technical evaluations or develop processes designed to upgrade iron ores; ability to prepare capital and operating cost studies. Salary open. Location, New York, N. Y. W7184.

Engineers. a) Technical representative, electro-plating, B.S. degree in chemical engineering, metallurgy, process chemistry, or chemistry. Graduate degree preferred. Four to seven years specific time on industrial electro-plating problems. Proven success in personal contact work and trouble shooting on technical problems; knowledge of electro-plating metals consumers in the automotive, electrical, ceramic, and allied industries. Salary open. b) Sales representative for nickel sales, A.B. chemistry, B.S. chemical engineering, metallurgy, or adminstrative engineering; or M.B.A. graduate with stress on marketing, sales management, or general business administration. Three to five years in industrial sales; preferably in steel and nickel metals. Salary open. Location, New York, N. Y. W7183.

Process Metallurgist with experience in the brass industry. Location, New Jersey. W7168.

Research Metallurgists, heavy on the physical side, for research on non-ferrous, basic studies and application for new uses. Salary open. Location, northern New Jersey. W7150.

Mechanical or Metallurgist for sale of extreme high-temperature refractories as used in aluminum, steel manufacture. Salary, $7500 to 8000 year. Location, northern New York State. W7129 (b).

Engineers. a) Physical metallurgist or metallurgical engineer, recent graduate, B.S. or M.S. desired, for position involving testing and development in connection with engineering of cryogenic equipment. Salary open. Location, upstate New York. b) Process metallurgist, M.S. degree preferred, with five to eight years research or production experience in melting practices in iron and steelmaking. Advanced research-development position in laboratory of leading and diversified company in metals and chemicals industry. Salary open. Location, northern New Jersey. Salary open. Location, midwest. W6371.

Engineers. a) Chief estimator, heavy industrial plants, graduate mechanical or mining engineer, with minimum of 10 years experience in estimating large industrial plants; including all mechanical, electrical, and civil engineering and construction for base metal plants, mills concentrators, smelters, and refineries. Will supervise small group of estimators. Salary high. b) Design engineers or designers,

(Continued on page 301)

WANTED

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RESEARCH METALLURGISTS

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Several openings exist also for recent B.S. graduates, in the fields described above and in projects dealing with steelmaking process analysis and development. For the B.S. graduate interested in a permanent research career, Pittsburgh offers unmatched opportunity for continued education at the graduate level.

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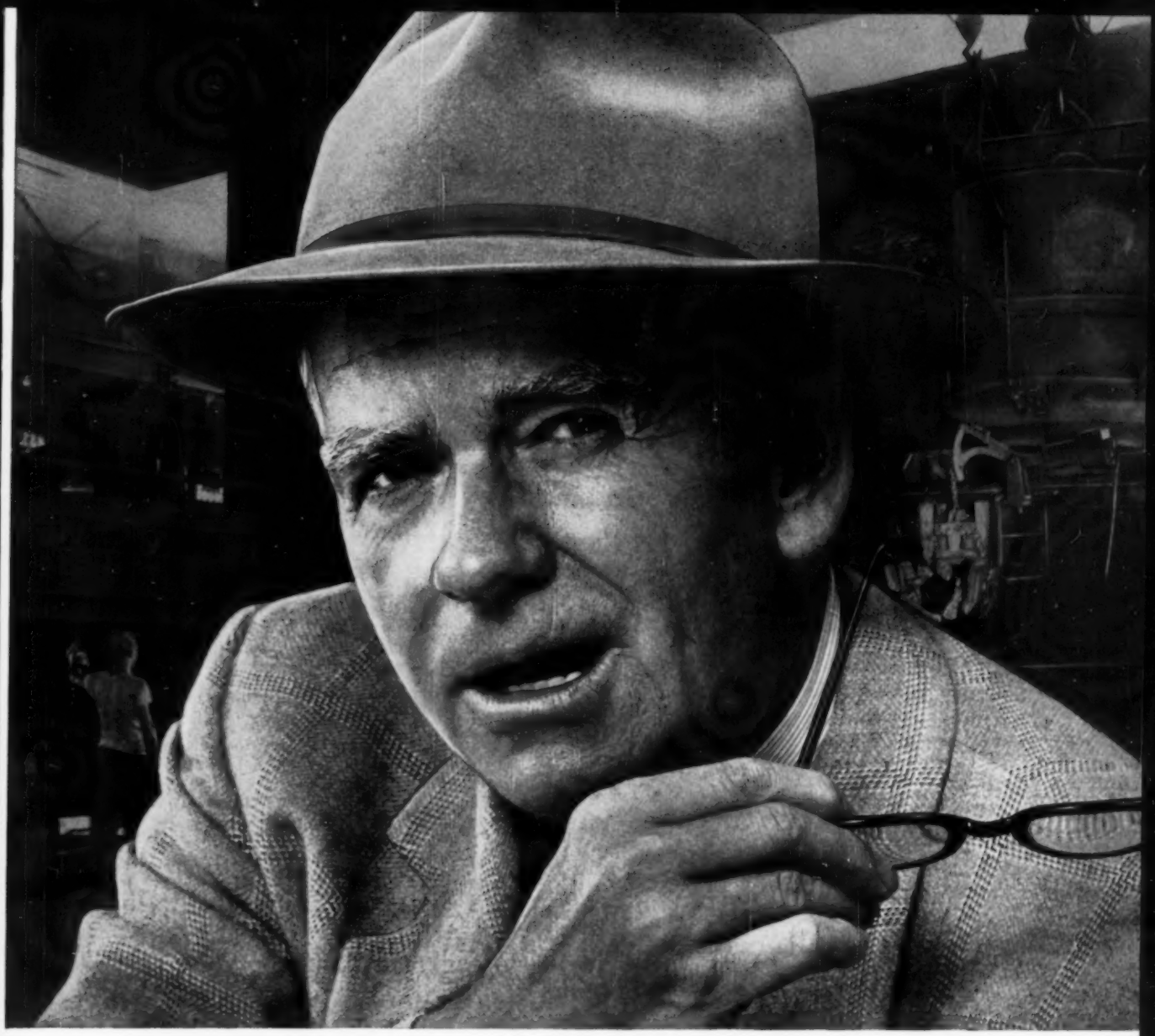

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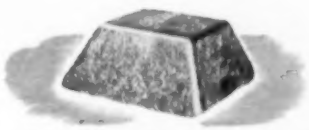

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Physical Laws and Effects, by C. F. Hix, Jr. and R. P. Alley, *John Wiley & Sons Inc.*, New York, 291 pp., $7.95, 1958—Authors Hix and Alley have combed current and almost-forgotten literature and come up with a collection of everyday, unusual, and generally unapplied laws and effects. Their belief is that inventions, innovations, and even industries may well spring up if more laws and effects are made readily available. The book is divided into three sections: description of laws and effects, cross reference by fields of science, cross reference by physical quantities. •

Trace Analysis, edited by J. H. Yoe and Henry J. Koch, *John Wiley & Sons Inc.*, New York, 672 pp., $12.00, 1957—Twenty-four recognized leaders in their respective fields of analysis have contributed their knowledge of trace analysis to bring together all or most of the methods and techniques used in this work. Based on papers presented at a Symposium on Trace Analysis in 1955, the book is divided into methodology, instrumentation, and sensitivity, separation, concentration, and contamination. A number of topics discussed are theory, application, sensitivity, precision, accuracy, sources or error, advantages, limitation, etc. of the various methods and techniques employed in working trace analysis. •

The Chemistry of The Actinide Elements, by J. J. Katz and G. T. Seaborg, *John Wiley & Sons Inc.*, New York, 508 pp., $14.00, 1957—The intent of the authors is to provide a comprehensive and unified treatment of the chemistry of the actinide elements for both the nuclear technologist and the inorganic and physical chemist. Considerable emphasis has been placed on nuclear process chemistry and the quantitative aspects of the subject, thus affording the opportunity of making the volume an introduction and a reference work at the same time. •

Early Engineering Education At Toronto 1851-1919, by C. R. Young, *University of Toronto Press*, Toronto, Canada, 150 pp., $3.95, 1958—Notable academic and political figures connected with the University of Toronto put in appearances as Dean Young narrates the history of the University. Illustrations of early buildings and former instructors in science and engineering aid in presenting an interesting account of Canadian education as the centuries changed. •

Tooling for Metal Powder Parts, by G. H. De Groat, *McGraw-Hill Book Co. Inc.*, New York, 242 pp., $7.50, 1958—Emphasis of this manual of production is on planning and tooling for structural parts; practical developments in the field are highlighted with special attention placed on the design of briquetting tools. Numerous illustrations and charts, a glossary and bibliography round out chapters on planning and economics for the metal powder process, design of structural metal powder parts, production of powders, preparation of powders, briquetting presses and practice, briquetting tools, sintering structural parts, and finishing operations. •

Automatic Process Control, by D. P. Eckman, *John Wiley & Sons Inc.*, New York, 368 pp., $9.00, 1958—Concerned with engineers interested in instrumentation, Prof. Eckman treats the important principles of automatic control, emphacizing block diagrams and frequency techniques in process control. Ten chapters cover the science of automatic control, process characteristics, controller characteristics, closed loop in automatic control, measuring elements, final control elements, process instrumentation, sinusoidal analysis and stability analysis. •

Metal Fatigue, edited by George Sines and J. L. Waisman, *McGraw-Hill Book Co. Inc.*, New York, 415 pp., $12.50, 1959—Recognizing the need for wider disseminations of knowledge on metal fatigue, the editors have sought out the leading authorities on the subject and combined their ideas into a "single author" approach. Six sections provide information on introductory factors, fatigue failure mechanisms, fatigue testing, analysis of influencing factors, load analysis, and structures and machines. •

The Structure of Steel, by Edwin Gregory and Eric N. Simons, *Philosophical Library Inc.*, New York, 176 pp., $10.00, 1958.—The text contains 47 line illustrations and 25 photographs which help to make the book a simple and non-technical explanation of the metallurgical structure of the various steels and steel alloys. The volume is intended for students, engineers, and buyers of steel. The important question of testing is fully developed, including the new laboratory methods. The basic chemistry of iron and steel is outlined with references to the effects of cooling from the liquid state. •

education

GRANTS AND FELLOWSHIPS

► **The National Science Foundation** has awarded 1100 graduate fellowships in the natural sciences and allied fields. In addition to the graduate fellowships awarded, the Foundation also announced the names of 160 winners of regular postdoctoral fellowships. Awards were made in furtherance of the Foundation's policy of encouraging outstanding college graduates to obtain advanced training in the sciences on a full-time basis.

► The **Atomic Energy Commission** has announced the approval of grants totaling more than $2 million to 41 colleges and universities for the purchase of laboratory equipment needed to expand their nuclear educational programs in the physical sciences and engineering. These grants are part of the Commission's program to assist in providing trained manpower for the atomic energy field.

The 41 grants include funds to seven engineering institutions for the purchase of teaching reactors. Recipients are West Virginia University, University of Wisconsin, University of Illinois, Kansas State College, University of Maryland, University of Texas, and University of Washington.

The seven reactor grants bring to 30 the total number of teaching reactors in operation, under construction, or to be constructed on campuses throughout the US with the help of Commission grants.

► **Carnegie Institute of Technology** is offering teaching assistantships, graduate fellowships, and research assistantships for the academic year 1959-1960. The fields open in this program are chemical, civil, electrical, mechanical, and metallurgical engineering. Other fields are nuclear science, chemistry, physics, and mathematics.

Carnegie will consider applications for the fall of 1959, until Feb. 1, 1959, although able and well-qualified candidates will be considered after this time. Address all correspondence to: *Dean of Graduate Studies, Carnegie Institute of Technology, Pittsburgh 13, Pa.*

► **Rutgers University** Materials Research Lab., New Brunswick, N. J., is the recipient of a National Science Foundation grant of $25,000. The major portion of the grant will be used to purchase an electron microscope that will enable researchers to heat and cool metals while they are under microscopic study. Two other attachments make possible the identification of diffraction, and convert the instrument to an X-ray microscope.

► Grants from **E. I. Dupont De Nemours and Co., Inc.,** were given to 150 colleges and universities in the company's annual program to aid education. This program is dedicated to study in fundamental research, and for strengthening the teaching of science and related liberal arts.

► The Board of Awards of the **Foundry Educational Foundation** has announced the presentation of five $1500 Wheelabrator graduate fellowships for 1959. The program is open to men under 28 years old who are either senior undergraduates or graduates registered with the F.E.F. In some cases, veterans and qualified men now employed in the foundry industry are eligible for the 1960 fellowships. Information may be obtained from the *Foundry Educational Foundation, Terminal Tower Building, Cleveland 13, Ohio.*

BOOKS & FILMS

► Donald L. Katz, chairman of the Dept. of Chemical and Metallurgical Engineering, **The University of Michigan,** is one of the authors of *Handbook of Natural Gas Engineering*, recently published by McGraw-Hill Book Co. The book covers a full range of topics from the very practical to the theoretical; 844 illustrations aid the reader.

► *Iron Blast Furnace Operations* from both the research standpoint and particularly the actual operating process viewpoint, is the title of a 15-lesson course for home study offered by the **Metals Engineering Institute,** a div. of ASM. Details on this and 17 other courses may be obtained from the *Metals Engineering Institute, Dept. NR-3, American Society for Metals, 7301 Euclid Ave., Cleveland 3, Ohio.*

(Continued on page 304)

Personnel

(Continued from page 298)

heavy industrial plants, graduate mechanical or mining engineers, with minimum of 10 years experience in design of large industrial plants. Prefer applicants with detailed knowledge of metals plants, such as mills, concentrators, smelters, and refineries. This includes crushing, screening, and materials handling experience. Salaries open. Location, west. W7281.

Metallurgist-Research, B.S. or M.S., qualified to deal with challenging metallography and metallurgical laboratory practices and studies, and preferably with knowledge of powdered metals. Will assist in research and new product development of refractory metallurgy; should have knowledge of physical chemistry and ability to use advanced laboratory equipment, tests, and instrumentation, also interest in electrolytical process development. Salary, $7800 to 9000 year. Location, San Francisco Bay area. S4142.

Metallurgist-Lead, chemical engineer or metallurgist, experienced in, or aptitude for, lead smelting for development, research, and operations. Salary, $6000 or better. Location, middlewest. S4181.

Metallurgist, with three to ten years experience in physical metallurgy, preferably in non-ferrous metals and development of new alloys; X-ray diffraction very desirable. Salary, $8400 to 11,400 year. Location, California. S4188.

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- "Cathodic bombardment etching of metals, alloys and ceramics—with special reference to U, Th and UO_2" by D. ARMSTRONG, P. E. MADSEN and E. K. SYKES.
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EDITORIAL

A Jigger of Wry . . . . (?)

It recently came to our attention that our Associate Editor, Mr. Burke, was once managing editor of the *Yale Record*, one of that breed known as *college humor* magazines. We visited Mr. Burke at his home not long ago, and while browsing through back issues of this magazine, we came upon a piece entitled *A Jigger of Wry*, where he had attempted to state the plight of the metallurgist in an alien society. We felt that his statement said something which many of us might have felt, but never expressed. Certainly his reference to the "Society of Holy Living Metallurgists" indicates that if action is necessary, it is up to us. *Ed.*

by J. J. Burke

IT was with mixed emotions that I read a slim, one-column article in a last week's edition of the [*Yale Daily*] *News* that carried the headline, "Metallurgy Department Celebrates 100th Year." Sadness overcame me when I thought of the countless undergraduates who would look at that headline and not even give it a second glance. I got downright mad, considering that it took one-hundred years of diligent scholarship for that fine little metallurgy department up on Mansfield Street to even rate a story in the *News*. It seemed that on this anniversary occasion, the case for metallurgy should be presented.

I approach this task with an almost religious zeal, for I know only too well the feeling of being snubbed at a cocktail party at the mention of metallurgy, and the mocking derision which the more liberally educated many hold out for this insignificant few, because I too am a metallurgist.

The first big obstacle that confronts the metallurgist is the title itself. A person who claims that he is in "Industrial Administration" immediately conjures up visions of family fortunes just waiting to be founded. A man who says "Chemical Engineering" promptly brings to mind that timeless phrase, "Better things for better living, through Chemistry." An electronics, aeronautical, or to go to the very limit, a nuclear engineer, brings to mind the very epitome of twentieth-century man, with all the myriad of devices which go to make up the Atomic Age. On the other hand, when one says he is in metallurgy, he draws a complete blank. No romantic visions of any sort spring forth in the mind of the populace, and the only reaction of any kind is a polite but completely disinterested, "That's nice, but exactly what is it?"

In the early days I tried to fight my way out of situations like this by making some idiotic comment like, "You know, we're the boys who turn lead into gold, heh, heh, heh," but this usually commanded a rather screwed-up smile which was intended to convey the thought that some day I should apply for admission to the human race.

Now of course, the idea behind questions like "What do you do?" or "What are you studying?" is their value as conversation starters, and the blame for the universal lack of knowledge about metallurgy must fall squarely on the shoulders of the Society of Holy Living Metallurgists. However, I would not be at peace with myself if I did not state that the attitude of the general public toward something they know nothing about, like metallurgy, is most often a fundamental incompatability which at times borders on a chemical repulsion. It is no wonder that metallurgists are so few and far between. Who would willingly commit themselves to this intellectual monastery? Well, I did, and you can take it from me that all this business about its being narrow and obscure is a lot of tripe; that's just what everybody thinks. Actually, metallurgy combines all that is *good* and *true* of chemistry, physics, and engineering, and is far and away the closest thing to scientific well-roundedness that is available. Of course, when writing papers, you're not asked to go after the moral, allegorical , or metaphysical points of view, but nevertheless you are inculcated with a *feeling* for the interplay of the sciences which can only be described as a philosophy.

This then, is the case for metallurgy. It is a fine profession, one well worthy to hold the keys that will unlock the doors to a brighter tomorrow for everyone. But to the few of us who call metallurgy our own, it is something more. Call it what you will, it is that something which enables us to bear the jests and jibes of our unknowing friends and to walk, head held high, with an inner knowledge that metallurgy—if I may be permitted to borrow a phrase from the English Department— is "Of an age, and for all time."

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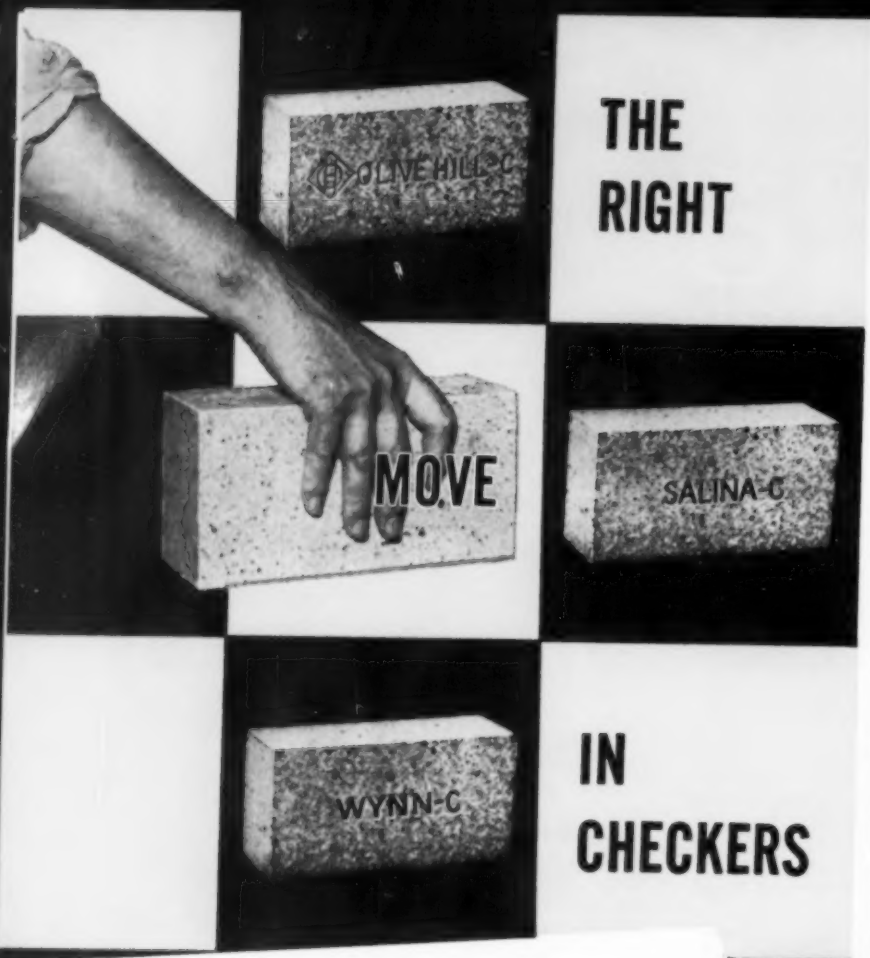

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(Continued from page 301)

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► The **Oak Ridge Institute of Nuclear Studies** has issued a brochure decribing the *Oak Ridge Research Participation Program*, which contains a directory of research opportunities involving the application of nuclear energy to basic sciences, agriculture, engineering, and medicine.

Research appointments for periods of three months to one year are available to university scientists. The appointments will be to the Oak Ridge National Lab. in general, with other appointments available to the University of Tennessee—AEC Agriculture Research Lab. and at the Institute.

Information and copies of the brochure may be obtained by contacting: *University Relations Div., Oak Ridge Institute of Nuclear Studies, P.O. Box 117, Oak Ridge, Tenn.*

SUMMER SEMESTER

► **Corrosion. Massachusetts Institute of Technology** offers a 1-week intensive course in fundamentals of corrosion reactions and corrosion control from June 22nd to 26th. The course is designed for those who have had previous instruction in corrosion. Lectures will emphasize reaction mechanisms and interpretation of laboratory and field measurements from the standpoint of modern electrochemical and metallurgical concepts. Inquire from *Prof. James M. Austin, Director of Summer Session, Massachusetts Institute of Technology, Cambridge 39, Mass.*

CONSTRUCTION

► **Worcester Polytechnic Institute** has contracted with the General Electric Atomic Power Equipment Dept. of San Jose, Calif., for installation of a nuclear reactor on the campus at a cost of $135,000. It will be used for research, demonstration, and teaching in nuclear science and engineering. Completion date of the 1 thermal-kw pool training reactor is scheduled for August 1st.

► **Newark College of Engineering** trustees have announced that a Newark industrialist, Thomas M. Cole, has donated $300,000 to the college for the establishment of a research foundation to assist the professional development of its graduate students and faculty instruction staff.

MISSILE SYSTEMS

► **The Pennsylvania State University's** Missiles Systems Engineering Seminar will be held from June 7th to 13th. No formal background in systems engineering is required, but some knowledge of mathematical methods in engineering is indispensable. The four main subject areas are: systems studies, typical patterns of modern military technical development, specific systems synthesis, and system analysis. Further information may be obtained from *Prof. Irving Michaelson, Dept. of Aeronautical Engineering* or from the *Extension Conference Center, The Pennsylvania State University, University Park, Pa.*

NUCLEAR ENERGY

► The **US Atomic Energy Commission** and the **American Society for Engineering Education** will sponsor six Summer Institutes on Nuclear Energy for engineering educators throughout the country. Purpose of these institutes in the fields of nuclear energy and the nature of nuclear reactor problems.

Five of the institutes for 1959 are for teachers who have had no special background in nuclear energy. Total capacity for the six institutes will be about 150 teachers selected by subcommittees of the ASEE Nuclear Committee on the basis of the candidate's experience and the instructional use to be made of this training.

Application for appointment may be obtained from the deans of engineering, directors of technical institutes, or from ASEE headquarters, Urbana, Ill. Returns should be made no later than March 1st to *Prof. W. Leighton Collins, Secretary of the ASEE, University of Illinois, Urbana, Ill.*

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Domestic uranium report

Domestic uranium production nearly doubled from 1956 to 1958, and 1959 will show another large increase, according to a report by J. C. Johnson, director, div. of raw materials, US AEC. In 1958 more than 5 million tons of uranium were mined in the western states. This ore was processed in local mills which produced concentrates containing about 12,500 tons of U_3O_8. Concentrates were sold to the AEC for approximately $238 million, greatly exceeded the combined value of domestic lead and zinc production.

Concentrate production in 1959 will approximate 18,000 tons of U_3O_8, having a value of more than $300 million. This may be the level of production through 1966. As of January 1st, there were 23 uranium processing mills in operation. Their combined rated daily capacity was 21,065 tons of ore per day. Domestic ore reserves were estimated at 82.5 million tons on January 1st.

Nuclear grade beryllium

Metal Bulletin reports that the Imperial Smelting Corp. has announced plans for the production of nuclear grade beryllium metal. The company has been investigating a thermal reduction method—under contract to the UK Atomic Energy Authority. This has resulted in the production of beryllium metal of the highest purity.

A new plant is being installed at Avonmouth. First stage for the production of limited quantities will be in operation by the end of the year. The plant, it is claimed, will be the first commercial production unit in the UK for virgin beryllium metal.

Udy—first commercial installation?

Koppers Co. Inc. has received a letter of intent from Universal Mineral Resources, a US concern holding iron-ore concessions in Equador, authorizing the company to make a *feasibility survey* of the Udy direct iron-ore reduction process for that area. Koppers has an agreement with Strategic-Udy to participate in laboratory developments at Niagara Falls and to undertake subsequent design and construction work on plants using the Udy process.

Equador's 250-odd miles of coastline has been estimated to hold as much as 200 million tons of recoverable metallic concentrates. The Udy iron-making process would make use of these iron-ore-laden sands.

Tungsten barrier weakening

Research at Fansteel Metallurgical Corp., North Chicago, Ill., has brought out new developments concerning tungsten. Until recently, tungsten parts had been made only by powder-metallurgy techniques because of the difficulty in fabricating the metal. This must be done above 800°F; below this temperature tungsten rapidly loses much of its ductility. New developments include:

- Forgings made in a series of steps or sequences, taking advantage of tungsten's increased ductility as it is subjected to further working. The forging techniques may be used for making simple rivets or electronic tube components.
- Seamless tungsten tubing by hot extruding. Deep drawing tungsten holds many possibilities.
- Fabrication of tungsten plate or sheet by spinning; this technique has far-reaching implications.

Beryllium closed-die forged

Wyman-Gordon Co., at the US Air Force plant in Grafton, Mass., has made a successful large closed-die forging of beryllium, thus overcoming a critical impediment to the use of metal in space and air flight. According to R. W. Stoddard, president of W-G, beryllium's brittle behavior has been a formidable barrier to overcome.

"A closed-die forging technique," he declared, "is capable of eliminating this brittle behavior and results in a much more ductile material. It also is capable of producing shapes that require a minimum of machining. These shapes so produced, now have the ductility and isotrophy of the order of the strong aluminum alloys while maintaining the inherently desirable properties of the metal." The forging was accomplished in a vacuum.

Flexible textile-form graphite

Manufactured graphite, refractory workhorse in numerous industrial and military applications, is now being produced in flexible fiber and fabric form by National Carbon Co., div. of Union Carbide Corp. The new process converts organic textile forms directly to graphite with a purity in excess of 99.9 pct. Any textile form, yarns, braids, felts, woven or knit fabrics, can be produced in this material. The process, for which patents have been applied, involves electrically heating a fiber or fabric to temperatures approaching 5400°F, changing the crystalline structure of the material to that of graphite in a thermo-chemical conversion. The end result is similar to manufactured graphite used for electric-furnace electrodes, nuclear reactor structures, or metallurgical molds.

Graphite textiles are resistant to attack by acids, alkalies, and organic compounds, except for those of a highly oxidizing nature, and are unreactive with many molten metals. They have excellent electrical and thermal conductivity, and are immune to shock.

National Carbon Co. is producing experimental quantities of graphite fibers and fabrics for test and evaluation by industry and military personnel throughout the country.

REPORTER

New Titanium Alloy

Improves Corrosion Resistance

Union Carbide Metals Co., div. of Union Carbide Corp., has announced the development of a new titanium alloy with much improved corrosion resistance. Containing in the neighborhood of 0.1 pct Pd, (representing 1 atom of Pd for every 2000 atoms in the alloy) the alloy is reported as resistant to boiling solutions of acids under "reducing" conditions without impairing titanium's inherent resistance to oxidizing acids.

[A reducing acid is defined by corrosion engineers as one which does not include any radical more oxidizing than its hydrogen ions. Examples are hydrochloric, phosphoric, and dilute sulfuric acids, all of which are commonly encountered in chemical processing.]

With this resistance to both types of acids, the new alloy should give greater flexibility to processing equipment and also guard against failure due to a sudden change in the chemical environment.

Applications

Possible practical uses include heat exchanges and condensers for marine applications, and stationary equipment where brackish water is involved. In chemical operations under batch condition, where corrosion is likely due to heated container walls during the draining period, substitution of the Ti-Pd alloy will eliminate corrosion.

Reported tests show that mechanical properties of the Ti-Pd alloy are identical with the properties of unalloyed titanium, with additions of up to 0.2 pct Pd having no effect on the tensile properties (including strength and ductility) of the titanium. The addition of 0.1 pct Pd to the metal decreases the rate of corrosive attack in a boiling 5 pct HCl solution from greater than 1 in. per year to less than 0.01 in. per year.

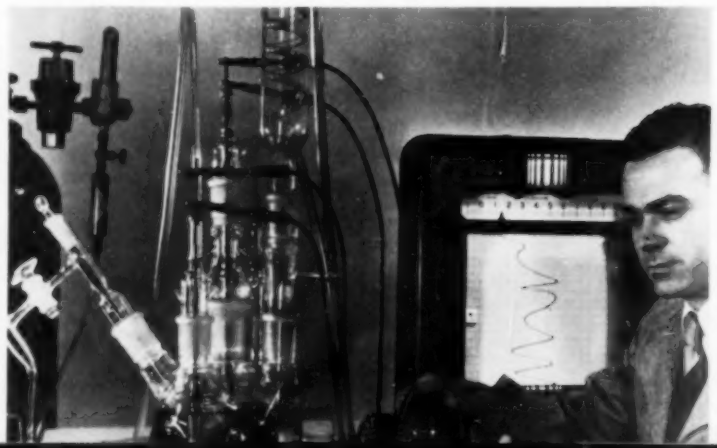
Corrosion resistant performance of titanium under the stress of reducing acid environment may be achieved by small additions of most noble metals. The peculiar advantage of palladium is that the average price is from 1/2 to 1/6 pct lower than that of other noble metals. Based on mid-March figures, 0.1 pct Pd adds about 28 cents per lb to the price of titanium. This figure should be considered with a price range for titanium mill products of $4 to $14 per lb in mind.

Developer explains theory

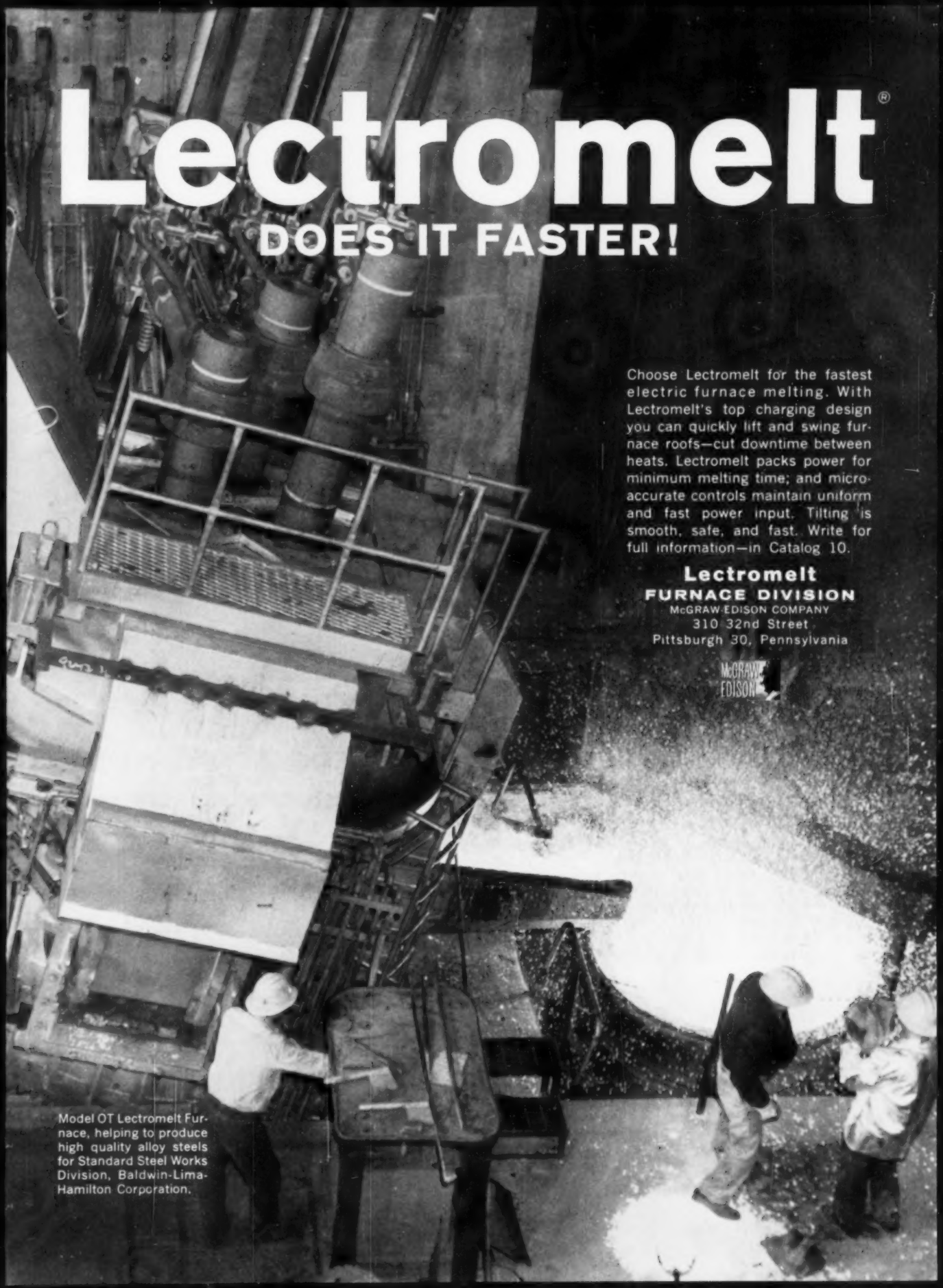
Credit for the new alloy was given to Dr. Milton Stern, who is technical supervisor of the metals research group at Union Carbide Metals' Niagara Falls, N. Y., research lab. In developing the new alloy, Dr. Stern advanced an electro-chemical theory for the role of noble metal additions on corrosion passivity. A noble metal is essentially insoluble in the corrosive environment and has a high exchange current for the hydrogen ion reduction process. When added to a metal, such as titanium, a noble metal appears to create a bi-electrode or galvanic couple at the surface of the alloy and serve as a site with a low hydrogen overvoltage. This results in passivity and a marked decrease in the rate of corrosion.

In a previous work, Dr. Stern had proposed that passivating-type inhibitors function primarily by creating a mixed potential more noble than the critical potential for passivity of the metal involved. The establishment of a potential more noble than some critical value is a basic concept which applies not only to inhibitors, but also to the phenomenon of anodic protection and the prevention of corrosion by galvanic coupling to suitable cathode materials.

Titanium exhibits unusually active values of critical anodic potential. Often, this potential is even more active than the reversible hydrogen potential of the solution. Thus, the theory postulates the establishment of passivity by alloying with elements having low over-voltage characteristics.



Electrochemical test set-up used in obtaining data on the dissolution of various metals by plotting anodic and cathodic polarization curves. The data prove that noble metal additions to titanium function in accordance with Dr. Milton Stern's theory.



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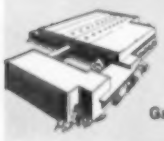

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SELECTIVE SMELTING OF LATERITIC ORES

Strategic-Udy shows how its differential smelting technique can be applied to the treatment of lateritic ores for the production of ferronickel, chromium iron, and refined steel.

by Marvin J. Udy and Murray C. Udy

LATERITES are the residual product of the weathering of many common types of rock. Deposits of laterites cover vast areas in tropical and subtropical areas; they vary greatly in composition, but in general, they consist of mixtures of hydrated ferric oxide and aluminum oxide in varying properties, and minor amounts of many other minerals.

The particular laterites with which this paper deals are quite common. Their iron content is high and, in fact, they would be good iron ores were it not for the presence of nickel and chromium. Their nickel content is about 1 pct, and they would be good nickel ores were it not for the high iron content. The 2 or 3 pct of chromium oxide present is usually considered a nuisance. These laterites are the weathering products of serpentine, which underlies the deposits.

This paper describes, among other work, what is probably the first production of quality steel from ores of this nature on a tonnage basis. At the same time, the nickel and chromium values are recovered separately.

The smelting process

The Strategic-Udy smelting process is a technique using various combinations of rotary kilns, reveberatory furnaces, and electric furnaces to recover metallic values from ores. The particular ore or combination of ores being used, together with the relative costs of fuel and electric power, dictates the exact combination of equipment to be used. In any case, heat is conserved until the ores leave as marketable products.

A distinct feature of the process is the electric-furnace smelting technique. It is not like the usual ferroalloy furnace techniques which operate with the electrodes surrounded and submerged with respect to the solid charge. On the contrary, the Strategic-Udy technique uses an open bath with the electrode position in respect to the molten slag controlled from about ½ in. above the slag to a maximum of 3 in. submerged in the slag, depending upon the temperature needs of the particular operation. The preheated or premelted charge material can then be fed directly into the hot smelting zone so that the reduction is almost immediate. Another feature of the process is the control of differential smelting and the high recoveries achieved by control of slag composition.

Not only can it process standard high-grade ores, but the Strategic-Udy process also has the advantage that should the ratio of iron to other metallic constituents in an ore be too high, or should there be impurities in an ore not wanted in the final product, selective reduction can be practiced by controlling the amount of reductant added. This gives a hot, enriched, purified slag to be further processed to the desired end product. This advantage allows low-grade and off-grade ores to be processed into high-grade end products. Valuable byproducts also result from the selective reduction. For example, high iron manganese ores can produce iron and ferromanganese; high iron chromum ores can produce iron and ferrochromium; high phosphorous iron ores can produce a small amount of high phosphorus iron and a major amount of premium-grade pig iron or steel; and as will be described in this paper, lateritic ores can produce ferronickel, pig iron or steel, and chromium iron.

Sizing of the ores is not critical to the process; fine concentrates may be used. For example, blast furnace flue dusts have been smelted by the process to high-grade iron or steel products with high recoveries and no dust problem. No sintering, pelletizing, or other means of agglomeration is necessary.

Another advantage is that reducing agents are not limited to special grades of coke. Anthracite coal, low volatile bituminous coals, coke breeze, or even certain lignites may be used.

The process as applied to the lateritic ores is illustrated in Fig. 1. The first step is a calcining operation in which the ore with the right fluxes and a certain amount of reductant sufficient to reduce all the nickel to metal and the iron oxide to a ferrous

MARVIN J. UDY and MURRAY C. UDY are vice president and research director, respectively, of Strategic-Udy Processes Inc., Niagara Falls, N. Y. This paper was presented at the 1959 Annual Meeting in San Francisco.

Table I. Analysis of Lateritic Material Used in Tests

	Cuban 1* (As Delivered)	Cuban 2* (As Delivered)	Cuban 2* (As Calcined)	Greek 1* (As Delivered)	Greek 2** (As Delivered)
Fe	42.4	45.4	52.95	52.37	49.0
Ni	1.37	1.38	1.59	0.79	0.73
Co	0.07	0.09	0.10	0.09	0.06
Cr	2.21	1.60	1.80	2.62	2.35
SiO_2	9.7	2.70	3.08	7.34	8.10
Al_2O_3	4.0	8.00	9.32	6.33	6.39
MgO	4.5	0.94	1.11	2.29	1.40
CaO	—	0.34	0.40	0.61	3.64
P	—	—	—	0.02	0.02
S	—	—	—	0.03	0.025
L.O.I.	13.8	16.3	0	5.62	7.27
Moisture	—	—	0	2.11	—

* Used in 100 kva tests.
** Used in 1000 kva tests.

state are heated to a temperature of 1000° to 1200°C. The exact temperature is the highest obtainable without ringing the kiln. The second operation is an electric-furnace operation that melts the reduced nickel and a small amount of iron to give a ferronickel product and a high-iron slag which is very low in nickel content. This hot slag is transferred to a second electric furnace where additional reductant is added, and a steel product of some 0.5 to 1.0 pct carbon content is produced. The chromium is retained in the slag along with a portion of the iron. This *high* chromium slag is taken to a third electric furnace where additional reductant is added and a high-chromium iron product is produced. While still hot, the steel from the smelting furnace is taken to a refining furnace where it is finished to ingot steel.

Equipment

Preliminary tests of the process were made at Strategic-Udy Processes Inc., Niagara Falls, N. Y. Equipment used included an oil-fired, 20-ft long rotary kiln of 20-in. diam and one 100-kva three-phase electric furnace of our special design built by Pittsburgh Lectromelt Furnace Co. The transformer delivers 60 to 360 volts phase voltage in 4 to 6 volts steps. Furnace shells with different types of refractory lining are available for this furnace. Magnesia lining was used for the bulk of the tests to be described here. Alumina linings were also successful.

A larger scale test was made at Strategic-Udy Metallurgical & Chemical Processes Ltd., Niagara Falls, Ontario, Can. The following equipment was used: 1) one 4-ft inside diam, 80-ft long kiln, oil or gas fired; and 2) three 1000-kva electric furnaces of special design built by Volta. They, too, have a wide range of voltage taps. Two of these furnaces are lined with magnesite and the third with rammed carbon paste.

Table II. Analysis of High-Iron Slags and Ferronickel from Cuban Laterites Smelted in 100-kva Furnace

Slag		Metal	
Ni, Pct	Fe, Pct	Ni, Pct	Co, Pct
0.20	48.14	—	—
0.08	44.08	—	—
0.11	47.27	17.86	—
trace	43.79	—	—
0.05	46.72	21.12	—
trace	46.69	21.22	2.20

Table III. Analyses of a Series of High-Iron Slags and Ferronickel from Greek Ores Smelted in 100-kva Furnace

Slag		Metal		
Ni, Pct	Fe, Pct	Ni, Pct	Co, Pct	C, Pct
0.05	44.4	10.61	0.56	—
0.028	42.6	10.34	0.54	—
0.055	45.5	10.07	0.52	—
0.067	46.7	—	—	—
0.060	47.0	9.4	0.56	—
0.068	44.4	8.8	0.47	0.13
0.045	46.4	8.5	0.37	—
0.045	42.6	8.75	0.40	—
0.075	44.7	8.0	0.35	—
0.025	46.1	—	—	—
0.023	42.3	—	—	0.13

Raw Materials

Ores from two different sources were used to make preliminary tests in the 100-kva electric furnace. Analyses of these materials are given in Table I.

Fluxes used included the following: 1) dolomite containing 39.40 pct MgO, 58.34 pct CaO, 0.49 pct SiO_2, and 1.58 pct FeO; 2) magnesite containing 89.2 pct MgO, 6.5 pct FeO, and 2.7 pct CaO; 3) magnesite containing 98 pct MgO; 4) quartzite containing 98 pct SiO_2.

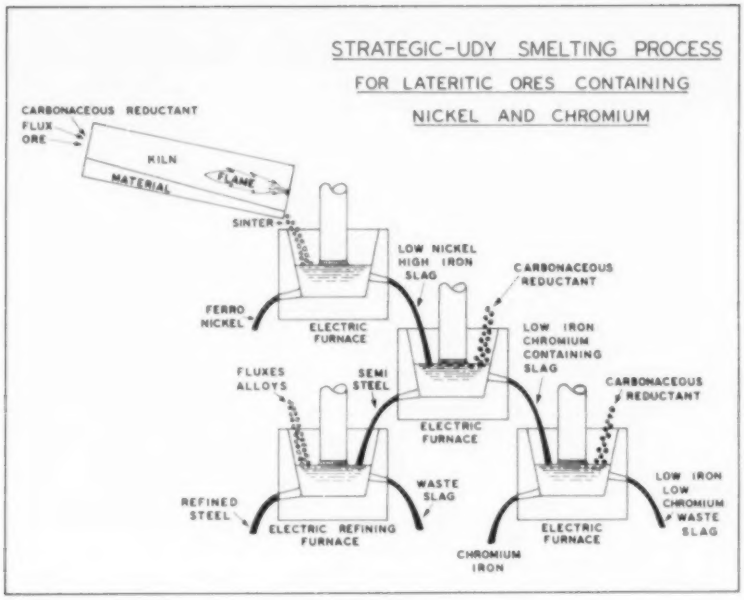
Reductants of the following analyses were used: 1) anthracite coal containing 5.0 pct volatile matter, 84 pct fixed carbon, 11.0 pct ash, and 0.59 pct sulfur; 2) bituminous coal containing 15.1 pct volatile matter, 77.3 pct fixed carbon, 7.6 pct ash, and 0.51 pct sulfur; 3) charred lignite containing 3.6 pct volatile matter, 57.3 pct fixed carbon, 39.0 pct ash, and 1.53 pct sulfur. These analyses are on a dry basis.

Experimental work

a) In 100-kva furnaces

Initial work in this series of tests was done with a small quantity of Cuban ore; dolomite and quartz were used for fluxing, and anthracite coal was used as a reductant. Table II gives the analysis of the high-iron slag and the ferronickel made from this ore. The material was charged cold into the furnace with no pre-reduction. The slag was smelted to give a steel product, while an attempt was made to recover most of the chromium in the metallic product. Analyses of the metal and the slag from these tests are as follows: 0.017 pct Ni and 2.42 pct Cr in the metal, and 1.97 pct Fe and 0.48 pct Cr in the slag.

The next 100-kva furnace tests were made at the request of Koppers Co. using the Greek ore shown in Table I. It may be seen that this ore is very similar to the calcined Cuban ore. Some 70 tests were made on the production of ferronickel from this material; anthracite coal and charred lignite were used with success in this operation. Table III gives the analysis of the products from a typical series of these tests. Dolomite was used as the major flux in this operation, and it gave a high-temperature slag which was refractory and protected the furnace walls from erosion. Silica was used as a minor flux from time to time to adjust the fluidity of the slag. The ore and flux were sintered together in the rotary kiln prior to charging cold into the furnace. Slag and metal were tapped at temperatures around 1600°C.



The nickel level in the metal was deliberately reduced during this series of tests shown in Table III. After the nickel was decreased to a level of about 5 pct, another series was made at about 15 pct Ni. The nickel level in the metal seemed to have no effect on the nickel level in the slag.

Practice in this operation was to operate with a fairly large pool of metal in the bottom of the furnace to serve as a collector for the nickel. Thus, any change in the level of the nickel content in the metal was gradual over a series of heats. Analysis of the ferronickel for chromium gave a nil result; carbon and silicon were low.

An analysis of composite slags from the ferronickel operation is as follows: 47.7 pct Fe, 0.065 pct Ni, 9.1 pct SiO_2, 10.0 pct Al_2O_3, 8.5 pct CaO, 5.9 pct MgO, and 3.6 pct Cr_2O_3. These slags were used to produce steel in the 100-kva furnace.

Table IV demonstrates that a steel can be smelted from the ferronickel slag without getting appreciable chromium into the metal. The nickel contents of the steel are higher than would be expected from the composite analysis. This resulted from contamination from some slag used to warm up the furnace in previous heats; they contained a fair amount of ferronickel *shot*. This shot contaminated the pool of metal in the bottom of the furnace and showed up in the analysis of the heats in Table IV. Even so, the nickel content of the steel is not excessive.

Not enough tests were made to determine the lower level of iron necessary to hold in the slag in order to prevent chromium from going into the metal, but it would appear to be about 6 pct. In any event, the relative slag volume at this point is fairly small.

Attempts to use charred lignite as a reductant in this operation failed because the lignite was not wetted by the slag and was not dense enough to settle into the slag where it would react quickly.

Because of the small amount of slag available, no attempt was made to produce an iron-chromium product in this series of tests.

b) In 1000-kva furnaces

In the prototype plant, using the 80-ft rotary kiln and the three 1000-kva furnaces, some 2300 net tons of the Greek ore, the analysis of which has already been given in Table I, was smelted continuously over a period of about seven weeks.

Two series of ferronickels from a production run of some 1500 tons of ore are described in Table V.

It was determined by microscopic examination that the nickel content left in the slag was primarily in the form of metal. This indicates that in a commercial plant, a holding furnace between the ferronickel furnace and the steel-smelting furnace would allow further settling of this nickel *shot* and would give a lower nickel slag for steel-smelting operation. A holding furnace would be desirable for material-flow purposes as well.

In the steel-smelting operation, the control of chromium in the metal was virtually absolute. The

Table IV. Smelting of Composite Slag from Ferronickel Production from Greek Ore in 100-kva Furnace

Slag		Metal			
Fe, Pct	Cr, Pct	Ni, Pct	Co, Pct	Cr, Pct	C, Pct
12.8	3.12	0.28	—	0.11	1.23
13.3	3.12	0.25	0.01	0.11	1.32
10.8	3.64	0.24	—	0.08	1.99

Table V. Ferronickel from Greek Ore Production Runs in Prototype Plant

	Series A	Series B
Wt of metal, tons	40.5	9.0
Analysis, pct		
Ni	6.4	11.7
Co	0.16	0.14
C	0.06	0.07
Si	0.20	0.08
S	0.06	0.06
P	0.008	0.008
Cr	trace	trace
Mn	0.005	0.005
Maximum Ni (individual heat)	10.0	22.0
Avg Ni in slag	0.05	0.11

Table VI. Analysis of Steel from the Smelting Furnace Prototype Plant Production Run

	Car 1	Car 2
Wt of metal, tons	53	57
Analysis, pct		
C	1.47	0.69
S	0.28	0.32
Si	0.15	0.15
Ni	0.15	0.21
Cr	0.09	0.10
Cu	nil	nil
Co	0.03	0.03
P	0.01	0.01
Mn	0.03	0.02

Table VII. Production of Chromium-Iron Product in Prototype Plant

Avg Feed Slag Analysis (from-steel-smelting furnace)	
Fe	10 pct
Cr	5 pct
Mn	1 pct
Chromium Iron	
Wt	8905 lb
Analysis:	
Cr	28 pct
C	6 pct
Si	0.5 pct
Mn	2.0 pct
Waste Slag	
Fe	0.24 pct
Cr	0.60 pct

Table VIII. Certified Analysis of Steel Heats Made By McLouth Steel Co. from Steel from the Smelting Furnace at Sumac—Greek Laterite Ores

	1st Heat	2nd Heat
C	0.06	0.20
S	0.045	0.045
Cr	0.05	0.07
Mn	0.32	0.89
Ni	0.20	0.26
Co	0.04	0.03
P	0.008	0.01
Si	trace	0.19
Cu	0.010	0.05

final 107 heats of metal showed an average of 0.07 pct Cr in the iron with 98.5 pct of the total Cr being retained in the final slag. Nickel was held at a low level. The two lots of steel listed in Table VI were shipped to McLouth Steel Co., Trenton, Mich., where they were processed into finished steel. More will be said of this later.

Some 26 tons of the final slag from the steel-smelting operation were further smelted to produce an iron-chromium product. Table VII gives the analyses of this feed slag and the products. Chromium and iron in the final waste slag were very low.

One interesting sidelight developed during these prototype plant tests. Apparently while some 95 pct of the Ni entered the ferroalloy, only about 19 pct of the incoming Co ended up in the ferroalloy, the balance being taken into the steel where it appeared at a level of about 0.03 pct Co. This seems to contradict the long-held assumption that cobalt necessarily follows nickel in the production of ferronickel.

Refining to commercial steel

Steel from the smelting operation at the prototype plant listed in Table VI was shipped to the McLouth Steel Co. where it was refined in two heats in a 60-ton magnesite-lined electric furnace. The first heat was made from the metal shipped in car two and the second from the metal from car one. This latter material was unintentionally contaminated with a small amount of stainless steel scrap at McLouth. The two heats were given no extraordinary amount of attention by the McLouth personnel and were melted, teamed, and rolled in accordance with the normal steelmaking practice. The only significant departure was the higher-than-normal sulfur content in the steel charge.

Since in the fully integrated process, molten steel will be charged directly into the steel-refining furnace, both melt-down and time-after melt-down were observed. The first heat required 2 hr and 30 min for melt-down for 53 tons, and 2 hr and 15 min for the refining period, during which time the sulfur and chromium were reduced to low levels, the carbon removed, and the manganese and silicon adjusted. Including delay because of a broken electrode, the second heat required 3 hrs for melt-down, after which the actual refining period was completed in 2 hrs and 15 min.

The first heat was aimed at producing a drawing-quality steel with low carbon and low sulfur, and these ingots were rimmed in open molds. The second heat was aimed at producing Class C ship plate and was killed with aluminum and teamed into big-end-up, hot-top molds. The final certified analyses of these two heats are given in Table VIII. These steels were fabricated by McLouth. Subsequent physical testing showed that they more than met the specifications for their grades.

Conclusions

The Strategic-Udy smelting technique as applied to the lateritic ores containing nickel and chromium has been demonstrated, both on a 100-kva scale and on a 1000-kva scale, the latter being large enough to provide engineering and cost data for commercial plant design.

The main product of the operation is a crude steel, low in chromium and nickel, which can be readily refined to standard steel grades. This refining has been demonstrated by the production of two commercial heats from steel from the smelting operation at the prototype plant. These two 50-ton heats of steel were well within specifications, both chemically and physically.

The smelting tests demonstrated that ferronickel in grades up to at least 20 pct Ni can be produced, leaving very little nickel to contaminate the steelmaking operation.

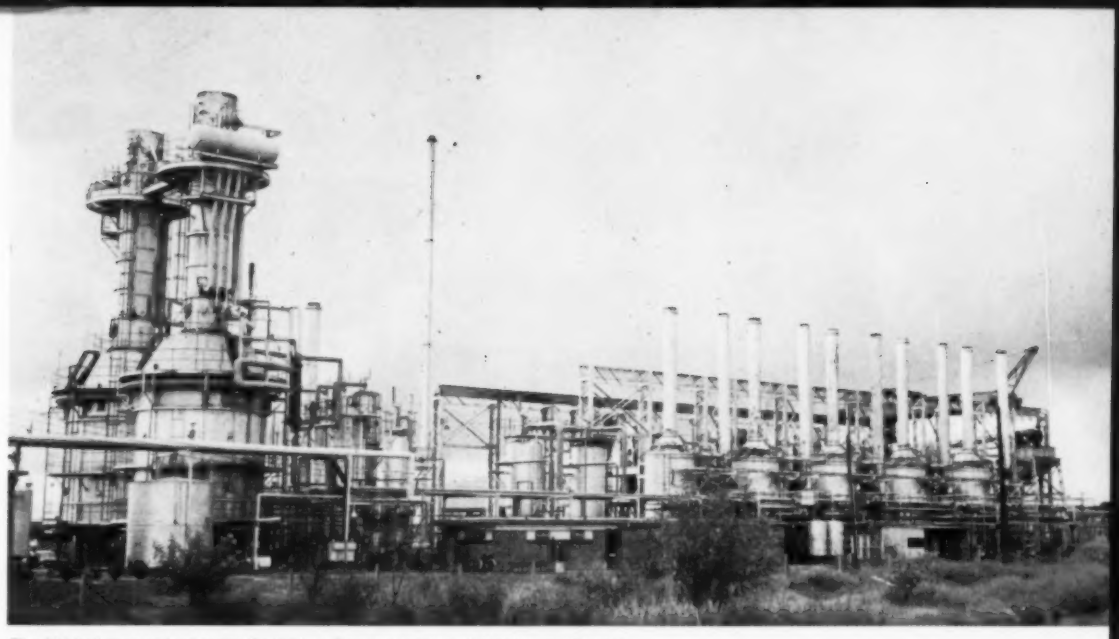
The close control possible by the Strategic-Udy process was demonstrated by the fact that 98 pct of the Cr was held in the steel-smelting slag.

A chromium-iron product of up to 40 pct Cr was made from the steel-smelting slag. Very little iron or chromium was left in the final waste slag.

These demonstrations may open the way to exploit large tonnages of ore hitherto not considered usable for steelmaking. That this exploitation will start in the near future is fully expected by the authors.

Marvin J. Udy

The Editors regret to announce that the author of this article, Marvin J. Udy, passed away on April 11. The Editors and staff of The Metallurgical Society extend their deepest sympathy to his son, co-author of this paper, and family.



The 200-tpd sponge iron plant Hojalata y Lamina located at Monterrey, Mexico.

SPONGE IRON BY THE HYL PROCESS

With stress being placed upon expanding steel capacity, particularly in many areas lacking capital and coking coal, much attention has been turned toward techniques for the production of sponge iron. Such a material can be used as a substitute for scrap in steelmaking furnaces. This article is a first-hand description of the production and utilization of sponge iron from a new process, the HyL process, in Mexico.

by F. Weston Starratt

Sponge iron is not new. In fact it is the product of what is probably the grandfather of all ironmaking processes. For a long period of time it was the major ironmaking technique, but the development of coke was the twilight era for sponge iron, except in certain areas.

Since World War II, steelmakers have been taking a second look at sponge iron, particularly as industrialization proceeds in vast areas of the world. The capital investment for, and the production from a blast furnace are enormous, and many regions are unable to supply the former or absorb the latter. Furthermore, coking coals are lacking in many countries.

One possibility of solving this problem may be the utilization of scrap in steelmaking furnaces. But scrap supplies are not always adequate, particularly in under-industrialized countries, and fluctuating scrap prices can be a deterrent from extensive utilization of this steelmaking raw material. Scrap may be the only answer in areas lacking in iron-ore deposits, but where iron ore does exist, direct iron-ore reduction processes, which do not require heavy capital investment or coking coal, are undoubtedly the answer. Some of these processes produce a porous material known as sponge iron.

Mexico as an example

Mexico serves as a good example of a country seeking to further its industrialization but lacking sufficient capital. Deposits of coking coal may be adequate, but their location and the inadequate transport system tend to create shortages.

Since World War II, Mexico's ingot steel production passed the half-million mark as the industry expanded its capacity. This included the installation of new blast furnaces. At the same time, Mexico's scrap imports mounted to the level of some 200,000 tons annually. Even in time of low scrap prices, this must have caused a certain drain in dollar reserves, since most of the scrap originated in the US. But with the uncertainties of the scrap market and the advent of higher scrap prices, there was ample reason for Mexican industrialists to look toward a more adequate utilization of Mexico's deposits of rich iron ore. This, together with the discovery of large quantities of natural gas within its borders, pointed toward the development of an economic means to make use of these two raw materials for the production of steel.

Iron ore, brought in by rail from the west, could easily meet gas piped in from the Gulf Coast at the industrial heart of Mexico, the city of Monterrey. Among several other steelmakers, the plant of Hojalata y Lamina is located in this city. During the past few years this plant expanded its steel making capacity through the installation of additional electric furnaces built by Lectromelt and, hence, felt the need for a cheaper and more reliable raw material basis than imported scrap.

Early in 1953, metallurgists were called-in from abroad, and the decision was made to install a tunnel kiln for the production of sponge at the annual rate of 12,000 tons per year. This installation did not prove satisfactory, and a small experimental Madaras retort was installed. Considerable difficulty was encountered with the retort in the operation of the pulsating valve at the temperatures required for ore reduction.

The negative results from these two lines of initial pursuit in sponge iron led engineers of Hojalata y Lamina to develop their own technique for the utilization of natural gas and iron ore for the production of sponge. Their experiments and pilot-plant results proved successful, and it was decided to erect an industrial-size plant. Engineers from M. W. Kellogg Co., initially called in to design a gas-reforming system, found themselves involved in the design of this 200-tpd sponge iron plant.

The plant, which went into operation in November 1957, proved successful enough for later public announcement of the development of a new sponge iron process, the HyL (Hojalata y Lamina) process. At the same time, plans were revealed for the installation of a 500-tpd plant, which is now under construction. M. W. Kellogg Co. became the world-wide licensing agent for HyL.

The process

The HyL process is a batch process in which rich, lump iron ore is reduced in a retort by hot, reformed natural gas. The gas enters the retort in a steady flow from the top of the reactor, passes through the ore bed, and then out the bottom of the vessel. There is, thus, no pulsating action, which involves difficult-to-solve mechanical problems with valves.

In the reforming process, the natural gas is first passed through a preheating coil in one of two Kellogg reforming furnaces. Next it is passed through a desulfurizing drum, and then through the reformer coils where natural gas and steam react to produce hydrodgen and carbon monoxide in the presence of a catalyst. The hot gas leaving the reformer flows through a waste heat boiler and is then sent to a scrubbing tower to quench the gas and remove the excess water. The cool, dry gas is then preheated in a heater which is fueled with spent reducing gas from the process. The hot, reformed gas comes in contact with iron ore in the primary reactor and is subsequently water quenched in a secondary gas tower to remove water formed in the reduction reaction. The gas is reheated and passed through a secondary reactor, which has been charged with fresh ore. The gas is again water quenched. Finally the dry, cool gas is used as fuel for the reforming furnaces and preheaters.

The reducing medium—hot, reformed natural gas—is blown through the ore bed in the reactors for a period up to 4 hr. Reduction may proceed to completion if desired, but economic considerations call for a 90 pct reduction which takes place during the given period. The final reduction temperatures in the reactor range from 1600° to 1900°F.

The average analysis of the dry, reformed gas being used at Hojalata y Lamina is as follows: 6.6 pct CO_2, 16.3 pct CO, 73.1 pct H_2 and 4.0 pct CH_4. Such a high H_2:CO ratio means that the overall reduction of iron oxides in the vessel is endothermic in nature. The necessary heat required by the hydrogen reduction reaction must, therefore, be supplied as sensible heat from the incoming gases.

Like other sponge-iron processes, the HyL process is incapable of removing gangue material from the iron ore, other than a reduction in the apparent lime content through calcining. The HyL sponge-iron process, therefore, achives the best results and economics through the utilization of high-grade ores or concentrates.

Lump ore in sizes from ¼ to 2½ in. is being used at the Hojalata y Lamina plant, finer size material preventing proper passage of the reducing gas through the bed, and larger lumps not being amenable to rapid reduction. Thus, fine concentrates in percentages higher than 20 pct—¼ in. can not be used in the process without agglomeration.

Unless steelmaking furnaces are prepared to cope with a high phosphorous charge, low phosphorous ores should be used in the HyL process, since it does not facilitate phosphorus removal. On the other hand, some 85 pct of the sulfur in the ore is removed in the HyL reactor.

Present Monterrey plant

The 200-tpd HyL sponge-iron plant at Hojalata y Lamina has five reactors, each holding about 15 net tons of ore. For the production of 1 net ton of sponge, some 21,000 N cu ft of natural gas and some 70 kva of power are now required.

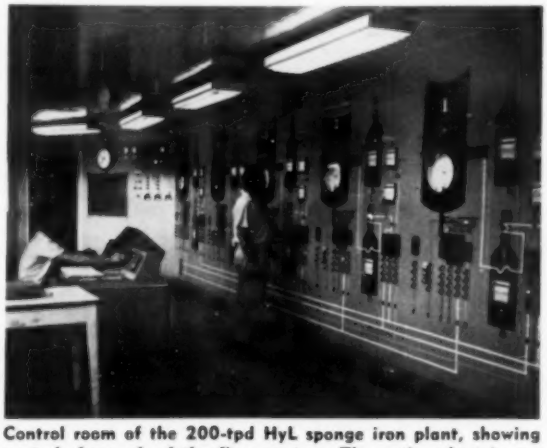
The reaction cycle requires 4 hr with an additional hour for dumping and charging. The reduction process for all reactors is controlled from a central control room. With each reactor at a different stage of the process cycle, it is possible for one labor crew to operate all five reactors. The entire 200-tpd plant requires only eight operating personnel per shift.

At the Hojalata y Lamina plant, Mexican iron ores from Durango and Pihuamo are being used in the production of sponge. A typical Pihuamo ore analysis is shown in Table I, while a typical analysis of sponge produced from this type of ore is given in Table II.

The hot sponge iron from a reactor is dumped into a bucket and moved by train to the adjacent steel plant where it is charged into one of the electric furnaces. With the present arrangement, sponge may be charged at temperatures up to 1200° F.

The new HyL plant

Now under construction by M. W. Kellogg Co. on a site adjoining the original HyL plant is the new



Control room of the 200-tpd HyL sponge iron plant, showing controls for each of the five reactors. The entire plant is run by an eight-man shift.

Construction site for the new 500-tpd plant. In the background is the electric furnace shop of Hojalata y Lamina at Monterrey, Mexico.

500-tpd sponge-iron plant.When completed late this year, it will be operated by Fierro Esponja, a subsidiary of Hojalata y Lamina. The majority of the new plant's output is expected to be used by Hojalata y Lamina to increase the percentage of sponge iron in its electric-furnace charge.

Considerably larger reactors will be used in this new plant, and this factor, plus a number of improvements in this design, will permit an increased thermal efficiency and generally lower operating costs. It has been estimated that the natural gas requirements may be reduced to about 17,000 cu ft per net ton of sponge produced,[1] and the required operating personnel are not expected to be much greater than for the present plant.

This new plant will obviously have lower capital costs per unit of output than does the existing plant, and it has been estimated that for the 500-tpd plant the goal of $29 to $30 per net ton per year will be more than achieved.

[1] P. E. Cavanagh: Direct Iron Ore Reduction, JOURNAL OF METALS, December 1958, pp. 804 to 808.

Carbon control

Probably the major problem encountered in the utilization of sponge iron produced by gaseous reduction techniques is the low and nonuniform carbon content of the sponge. For ease in steelmaking, the sponge must be sufficiently high in carbon and uniform from batch to batch so as to provide a bath carbon content between 0.15 and 0.25 pct after meltdown in the furnace. Until recently, this had not been the case at Hojalata y Lamina.

Under normal operating conditions, only a minute amount of carbon is introduced into the HyL sponge. This carbon derives from the gases, but the relatively high temperatures in the reactor are not conducive to the exothermic decomposition of carbon monoxide into carbon and carbon dioxide. Furthermore, cracking of the remaining methane in the reducing gas does not result in the deposition of carbon at the temperatures and pressures encountered.

In order to solve this important problem, a final low-temperature stage has been incorporated in the heating cycle of the HyL reactors. At this point, the cracking of natural gas passed directly through the bed of hot sponge iron can result in the deposition of a fine deposit of carbon in the pores of the sponge. This final phase of the process requires from 10 to 15 min, depending on the amount of carbon required in the sponge. Currently about 0.3 pct C is contained in the sponge at Hojalata y Lamina, although it is claimed that higher carbon contents can be achieved.

Steel from HyL sponge

There are no insurmountable problems in making steel from HyL or any other sponge, claims a leading electric-furnace consultant called in by Hojalata y Lamina to advise them on sponge melting in electric furnaces.

The electric furnace shop at this plant has one 45-ton and two 75-ton Lectromelt furnaces. These furnaces have now been in operation for a year on a 50 pct sponge charge. Many early difficulties were encountered in melting this sponge because of its low density and conductivity, but now that adequate melting techniques have been developed, results are as satisfactory as when melting scrap.

Steel has been made from several 100 pct sponge-iron charges, and the results have been quite good, but because of circulating scrap, it is not expected that more than a 75 pct sponge charge will be used as an operating basis. At present, a 50 pct charge is being used because of a lack of sponge, but the new 500-tpd plant will mean that, by the end of 1959, the charging routine will be on the basis of 75 pct sponge iron.

Table I. Analysis of Pihaumo Iron Ore Used For Sponge

Total Fe, Pct	66
Insolubles, Pct	4
Al_2O_3, Pct	0.2
CaO, Pct	0.5
P, Pct	0.2
S, Pct	0.2

Table II. Analysis of Sponge Made from Pihaumo Iron Ore

Metallic Fe, Pct	85.4	(A)
Total Fe, Pct	91.0	(B)
Reduction, Pct	93.85	(A/B)
C, Pct	0.4	
S, Pct	0.014	
Insolubles, Pct	6.0	

The melting technique now being followed at Hojalata y Lamina is as follows: a small quantity of scrap is first charged on the bottom of the furnace, and all the sponge iron is next charged, high along the walls and low in the center. The electrodes are lowered into this center depression. For the first 3 to 5 min some 30 pct of the power is applied, and the charge is heated by induction. As the temperature rises, more current is used, and the charge begins to melt from the bottom up. After the melt-down, which requires substantially the same time as with an all-scrap charge, an acid slag is flushed from the furnace. Then the remainder of the scrap is charged into the furnace, and lime is added. From this point, operations proceed more or less as in normal electric-furnace operations.

During 1958, it was customary to add some 1.3 pct graphite to the charge in order to raise the carbon content of the melt. A level of some 0.30 pct C in the bath insures a sufficently high final carbon content in the metal and a low iron-oxide content in the flush slag. Carbon control has not always been completely successful, but in recent months between 80 and 90 pct of the heats have attained the desired range of carbon. Two means for improving this have been suggested: increasing the carbon content of the HyL sponge, and charging a certain quantity of pig iron into the electric furnace, as is the practice in certain Swedish melting shops where sponge iron is used.

In 1957, lime consumption per metric ton of steel was 68 kg with no sponge iron being used. This increased to 75 kg per metric ton of steel in 1958 when a charge composed of 50 pct sponge was being used. This means that the 6 pct acid gangue material in the sponge iron resulted in a 10 pct increase in lime consumption.

Metallic yield of steelmaking, whether by use of scrap or sponge, has proved to be essentially the same at Hojalata y Lamina. The tonnage of steel produced per heat is also comparable. On the 75-ton arc furnace, an average of 4½ heats per 24-hr day were made on the all-scrap charge, and same number are now being made on the 50 pct sponge charge. The plant's capacity has thus remained on the order of 300,000 net tons of ingots per year.

Power consumption

While the HyL sponge in current use at Hojalata y Lamina carries only 6 pct gangue, this amounts to some two tons of material in the 75-ton furnace, and a certain amount of energy is required to bring it up to temperature and to melt it. On the basis of a 100 pct charge of this sponge, an increase of 12 pct in power consumption was noted. With a higher gangue content there would, of course, be a greater difference in power consumption.

One factor stressed by Hojalata y Lamina on the question of power consumption is the much more uniform power requirements for melting sponge. Accounting for this is the fact that the empty spaces present in the scrap charge disappear when sponge is charged, thus avoiding energy radiation through these spaces to the refractory lining of the furnace. Also, with the electrodes completely surrounded by compact sponge iron, a greater portion of the heat is absorbed by the charge. The overall result is that the increased power consumption in melting sponge is, in practice, only slightly in excess of that required for melting scrap.

Steel quality

Some 80 pct of the steel currently being made at Hojalata y Lamina is low-carbon, deep-drawing steel of the following analysis: 0.08 pct C max, 0.30 to 0.45 pct Mn, 0.20 pct P max, 0.045 pct S max, 0.022 pct Cu max, 0.06 pct Ni max, and 0.01 pct Si max.

A major reason for the enthusiasm with which Hojalata y Lamina has adopted sponge iron is the difficulty formerly encountered in keeping the residuals low. Copper and nickel were particularly difficult to maintain at low levels with the scrap which was being used. By using sponge iron, the number of off-heats due to high residuals has been reduced to a fraction of its former value. This factor is emphasized as an important reason for the utilization of sponge iron in the production of high-quality, deep-drawing steels.

Conclusions

A picture has been presented of some of the problems faced by Mexican steel producers and how they have solved them, in part, by the development of a new method for the production of sponge iron, the HyL process. This process is uniquely suited to the Mexican situation with its natural gas and high-grade iron ores. But such a combination of resources also exists in many other areas where it is desired to expand steel production.

By utilizing a high-grade ore or concentrate, HyL produces a sponge sufficiently low in gangue to be converted directly into finished steel in the electric furnace. Fines can not be used without agglomeration.

On the economics of producing HyL sponge, each plant and each region obviously has a different set of cost factors. But two general observations may certainly be made. For one thing, capital costs are certainly less than for the traditional blast furnace, particularly if only a moderate-sized plant is envisaged. Furthermore, the economics of the 200-tpd plant at Hojalata y Lamina must be particularly interesting, otherwise one could hardly anticipate the expenditure of additional funds to build a 500-tpd plant.

In regard to melting sponge iron, Hojalata y Lamina is currently melting a 50 pct sponge-iron charge, which it will increase up to 75 pct sponge when more becomes available. They have shown that it is quite possible to melt charges up to 100 pct sponge.

The change-over from scrap to sponge at Hojalata y Lamina has resulted in a considerable decrease in the number of off-heats due to high residuals, but the use of sponge iron has intensified the problem of keeping the carbon content of steel within the desired limits. The sponge has tended to carry less than the minimum amount of carbon, and there has also been some variation in carbon content. Much has been done to alleviate this problem, and possibly the present final treatment of the HyL sponge with natural gas may have solved it.

★ ★ ★

We came away from our visit to the Hojalata y Lamina steel plant at Monterrey, Mexico, with the feeling that HyL sponge iron was certainly there to stay. What problems remain are apparently being solved, and this process, engineered by the Mexican firm and M. W. Kellogg Co., may indeed be an answer for many other parts of the world.

BROOKHAVEN

At its Eleventh Year

Brookhaven National Laboratory is now in its 11th year. One of the major research facilities, the graphite reactor, has supported many programs in the research since 1950. Under current construction is the Alternating Gradient Synchrotron, which will accelerate protons to energies of 25 Bev. The past and present research activities of the Laboratory, and its organizational history, are reviewed in brief.

by Dennis Puleston

NEAR the geographical center of Long Island, 70 miles due east of New York City, the huge scientific research establishment known as Brookhaven National Laboratory has been developing steadily since its founding in 1947. At that time, it was considered the Country's boldest and biggest investment in long-range, fundamental research, an imaginative effort to build up a backlog of pure learning in the new science that had sired the Bomb. The passing of Brookhaven's 10th anniversary presents an appropriate occasion to review its development to the present, and to consider what little can now be foreseen of its future.

At the end of World War II, this country's scientific effort could be compared to an animal emerging from its hibernation after a long, hard winter. In order to survive, it had consumed its layer of metabolic fat, and now, to bring itself back to full vigor, it must rebuild that layer. For 5 years, from 1940 to 1945, our science had been living off its fat, making war with the stored capital of its accumulated learning. In an attempt to rebuild that capital, an initiatory group of representatives from a number of northeastern universities discussed the problem with the Manhattan Engineer District, from whom they received encouragement. They, therefore, proceeded in mid-1946 to form Associated Universities Inc. (AUI), a nonprofit educational corporation. AUI contracted with the Manhattan District, and later, upon its formation, with the Atomic Energy Commission, to establish and operate Brookhaven.

Under its charter, AUI is an agency through which universities and other institutions can cooperate with one another and with the Government for the support and mutual use of research facilities, for the development of fundamental scientific knowledge and for educating and training of technical, research, and student personnel. Nine universities are represented in AUI: Yale, Columbia, Princeton, Harvard, Johns Hopkins, Cornell, Rochester, Pennsylvania, and Massachusetts Institute of Technology. Each member university names one scientist and one administrator to AUI's board of trustees, which makes the broad, general policies of Brookhaven. Actual management of the Laboratory is vested in a director who reports to the board.

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From the outset, Brookhaven has emphasized the cooperative nature of its research program. To this end, much of the staff consists of visiting scientists, some on leave from other institutions, others pursuing graduate work. The Laboratory is not restricted to people from the nine sponsoring universities; staff members of other institutions are equally welcome. The aim of such policies is to encourage the cross-fertilization of minds throughout the scientific community, and to employ the great diversity of those minds that is now necessary to the elucidation of fundamental knowledge. It is a striking characteristic of modern nuclear science that an increasing degree of concerted effort is needed in attacking the basic problems.

Brookhaven's beginning, at least in the visual sense, was not spectacular. Of all the Commission's great ventures, it probably has the least eye-appeal; in 1947, when it was taken over from the Army, it was nothing more than a cluster of several hundred drab, barracks-type buildings and a small hospital, linked by muddy roads, and set in over 6000 acres of parade grounds, scrub oak, and pine woods. However, the nucleus of the Brookhaven staff lost no time in converting many of the existing buildings into offices, labortories, and dormitories.

Research Reactor

Completed and brought to criticality in 1950, the reactor was the first large-scale pile to be designed specifically to support fundamental research programs. Compared now with the current rapidly expanding families of reactor concepts, it is a veritable Model T. The design was based upon the experience gained during the war years with the production reactors at Oak Ridge and Hanford, and was chosen because of the ready availability of its primary component materials, reactor-grade graphite and natural uranium metal. The concept was based upon the requirement for large research areas, so that many projects could be supported simultaneously. In spite of its high initial cost (over $25 milllion) and the heavy power requirements of the cooling system (5000 kw), this reactor has paid off the investment in rich research dividends, prov-

ing itself as a valuable and versatile experimental tool.

The reactor proper consists of a 25-ft graphite cube separated into two halves by a 2.75 in. gap. Sixty thousand graphite blocks with a total weight of 700 tons make up the core, which is penetrated by 1368 round, parallel fuel channels, spaced 8 in. between centers. The graphite serves to moderate, or slow down the neutrons so that the chain reaction can be maintained. Cooling is provided by a stream of air, which is drawn by five 1500-hp fans into the central gap; it then flows out through the channels, to be exhausted out of a 320-ft stack. The graphite cube and air chambers are enclosed in a 5-ft thick shield of high-density concrete, reinforced with steel punchings. The shield is penetrated by many horizontal experimental holes of various sizes for in-pile irradiation studies, and for the emission of beams of neutrons for use with equipment installed at the reactor faces. There are also conveyor systems for sending irradiation samples through the reactor at selected flux and time conditions. By means of pneumatic tubes, isotopes of short half-life can be shot directly from the heart of the reactor into awaiting experiments in adjacent laboratories.

Until early in 1958, the reactor had operated at a fairly constant power level of 28 Mw, at which level a thermal neutron flux of 5×10^{12}n per sq cm per sec was obtained. However, with the increasing availability of highly enriched fuel, it was decided to convert from normal uranium, and thereby obtain a higher flux. The reloading program was initiated last spring. Each of the new 24-in. fuel elements are made up of three plates, each plate 0.060-in. thick, containing about 5 g of U^{235} in an aluminum matrix, clad with aluminum. With this conversion, the required mass of U^{235} is reduced from 385 kg contained in the natural uranium to 57 kg in the enriched elements. The central neutron flux has now increased to 2.5×10^{13}n per sq cm per sec, which represents an almost sixfold increase in useful neutron flux over that obtained with the previous natural uranium loading. An additional advantage is gained in the lowering of the operating power level from 28 to 16 Mw; this, together with the lower resistance to air flow with the new fuel elements, requires less pumping power for the cooling air. Also, the new elements are inherently less subject to rupture by oxidation, canal contamination, and coolant contamination, difficulties which are invariably associated with canned natural uranium fuel.

Particle accelerators

As further research tools for the nuclear scientist, Brookhaven has a variety of particle accelerators. These machines accelerate electrically charged particles, such as protons and electrons, to high speeds by means of electrical voltages. The highly energetic and fast-moving particles are directed at target atoms, whose nuclear properties can then be observed and studied. One of these machines is an electrostatic accelerator producing potentials up to 4 million electron volts (Mev) inside a large steel tank; it accelerates protons, deuterons (nuclei of heavy hydrogen), and alpha-particles (nuclei of helium) for very precise experiments on nuclear structure. In a second type of accelerator, the 60-in. cyclotron, beams of 11-Mev protons, 20-Mev deuterons, and 44-Mev alpha-particles are obtained.

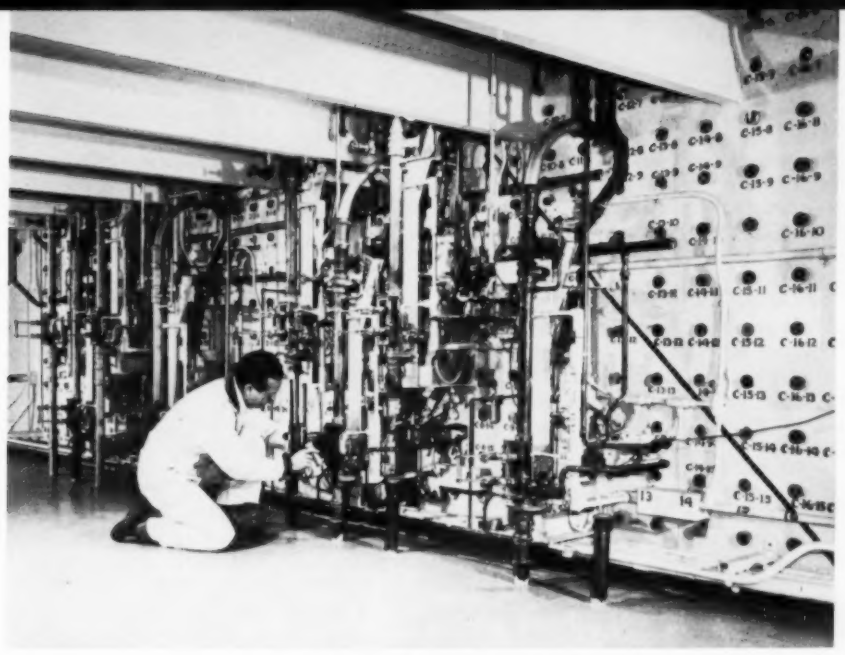
The largest operating accelerator at Brookhaven is a proton synchrotron, which has received the name Cosmotron, because it produces energies (3 Bev) as high as some of the primary cosmic rays from outer space. In this machine, protons (hydrogen nuclei) are guided in a vacuum chamber by a doughnut-shaped system of electromagnets. They are forced to travel always in the same circular orbit by increasing the magnetic field during the acceleration period. At each revolution around the 75-ft diam magnet ring, they are given an incremental 1000-v boost in energy by a radio-frequency acceleration station. At the end of the 1-sec acceleration period, having traveled some 150,000 miles, the protons are allowed to strike the target, which has been inserted inside the vacuum chamber, but at a smaller radius. Nuclei of the target atoms are shattered into fragments, ranging in size from large chunks of the original nuclei to their component nucleons (neutrons and protons). Mesons, the particles intermediate in mass between electrons and nucleons, are created by the conversion of energy into matter. Some of these (π-mesons) have positive, some negative, and some have no charge. These sub-nuclear particles exist outside the atom for only a fraction of a millionth of a second before they decay into other particles, or change their mass completely into energy. Nevertheless, their brief lifetimes make it possible for the particles to be recorded in devices such as electronic counters, cloud chambers, bubble chambers, and photographic emulsions. Thus, their mass, electrical charge, and other properties can be determined.

At the time when the first experimental beam was obtained from the Cosmotron in 1952, this was the world's most powerful particle accelerator. Very soon, the Bevatron at the University of California's Radiation Laboratory outpaced it, with protons of 6.2-Bev energy. Then, in April 1957, the giant synchrophasotron at Russia's Dubna laboratory reached an energy of 10 Bev. With the steel requirements for the magnets for this latter machine reaching the staggering figure of 36,000 tons, man's quest for controlled nuclear interactions at higher and higher energies might well have ended here, for economic reasons alone, except for a newly-developed concept. This, known as the alternating gradient *strong focusing* principle, now makes it economically feasible to build synchrotrons many times more powerful. The new theory provides a method for focusing protons in their flight so they will group themselves in a beam so narrow they can travel in a vacuum chamber of relatively small cross section.

Alternating gradient synchrotron

A new synchrotron has been designed and is now being constructed at Brookhaven; it will use the strong focusing principle to accelerate protons to an energy of more than 25 Bev. This machine, the Alternating Gradient Synchrotron (AGS), requires only about 4000 tons of steel to achieve the above energy, 1/9 the amount in the Russian 10-Bev machine, and 2/5 of that in the 6-Bev Bevatron.

Perhaps the best way to describe the operation of the AGS, which is scheduled for testing in 1960, is to follow a beam of protons from its point of origin to the ultimate target. Hydrogen gas is supplied to a cold cathode discharge in an ion source. The nuclei of the gas atoms in the discharge pass through a small aperture in the cathode to a Cockroft-Walton



A pneumatic tube system has been installed on one face of the Brookhaven reactor, enabling samples having short half-lives to be irradiated, and, in a matter of seconds, be delivered back to the face or to adjoining laboratories. Above, an operator is inserting a sample into one of the pneumatic tubes.

generator. This accelerator raises the energy of the protons to about 750,000 ev. The second acceleration stage is provided by a 50-Mev linear accelerator (linac), where the beam of particles is guided through 124 drift tubes down the center of a 110-ft cylindrical tank, having a number of high voltage electrodes that impart the desired energy.

At the end of the linac, the beam is guided into the main synchrotron ring, which consists of 240 magnet sections spaced in a circle ½-mi in circumference. At each of 12 locations around the ring, a radio-frequency acceleration station gives the beam an 8000-v boost in energy. Thus, for each circuit of the ring, the energy gain is 96,000 ev. Consequently, in order to reach the final energy of 25 Bev, the protons must make about 260,000 circuits, or travel 130,000 miles. Toward the end of the 1-sec acceleration period, they have reached to within a fraction of 1/10 of 1 pct of the velocity of light, or over 186,000 miles per sec. At this tremendous speed, the beam is bent magnetically to strike the target, or is deflected completely out of the vacuum chamber into an experimental area. Ejection increases the usefulness of the machine, since by this means a number of separate experiments can be installed along the beam path. However, an external beam presents a radiation problem that requires the erection of a heavy earthen dike as a *backstop*. As additional shielding, the entire ½-mile tunnel housing the magnet ring has been buried under a 10-ft bank of earth. In the main target building, 14,000 tons of high-density concrete shielding are required to straddle the ring.

In the above brief description of the principle characteristics of the AGS, it has not been possible to convey the high degree of the many meticulous calculations required to meet the design requirements. Possibly, an idea of these exacting requirements can be derived from a more detailed description of one of the AGS components, the magnet assembly. Each of the 240 magnet sections must be so precise in its guiding and focusing functions that the protons must not impinge upon the sides of the vacuum chamber, or their energy would be dissipated. Each section must be nearly identical in property, to a degree heretofore considered almost impossible. Each magnet, roughly C-shaped in 3-ft sq cross section, is about 90 in. long, and is made up of some 2800 laminations of 0.031-in. steel, with 1-in. end plates. The plates are compressed together by a force of 80 tons and held by eight longitudinal straps welded to the outer periphery. The laminations are insulated from one another by a special resin to inhibit eddy currents. The elliptical vacuum chamber, in which a pressure of 10^{-6} will be maintained, has inside dimensions of 3x6.5 in.; it is centered in the gap between the magnet poles. It is the shape of the poles that accomplishes the strong focusing effect so essential to keeping the protons in orbit. About half of the 240 magnet sections are bowed outward, to provide sharp vertical focusing; the other half are bowed inward for strong horizontal focusing.

An Electrical Grade M-36 sheet steel containing about 1.80 pct Si and 0.03 pct C was selected to best meet the exacting requirements. This steel was selected not only for its magnetic properties, but because of its flatness; even the most minute irregularity in surface could distort the magnetic field and thus reduce its effectiveness. Since even the highest quality sheets vary in properties, not only from one heat to another but from sheet to sheet, and even from one part of a sheet to the other, a technique was developed for shuffling the sheets like a deck of cards, according to a carefully devised plan. Thus, any possible imperfections, however minor, should be distributed equally throughout the magnet ring. For the actual positioning of the magnet sections, with reference to the primary survey monuments, a precision to 0.001 in. has been

obtained. Each monument is driven into the earth in such a way that it is mechanically separate from the tunnel foundation and ring supports. And yet, even this is not sufficient; there may be future, unpredicted soil movements, and it is to monitor these imponderables that a program for periodic resurveys is planned.

Reactor technology

It appears to be a far cry from particle physics to the development of new reactor systems and reactor components that will advance the use of nuclear energy for industrial power. Yet even here many basic problems must first be solved—problems including the chemistry of elements of special interest in nuclear energy, such as uranium and plutonium; the metallurgy of reactor materials; and the properties of such materials when subjected to intense neutron irradiation. To attack these problems, Brookhaven is conducting a vigorous program in nuclear technology, including all phases of reactor physics, chemical processing, metallurgy, and mechanical design.

A great part of the present effort in these fields is currently directed toward the design of a Liquid Metal Fuel Reactor (LMFR) for the production of useful electric power. Basically, this design utilizes, as a fuel, molten bismuth in which highly enriched uranium is dissolved (about 500 to 1000 ppm). In addition, up to 350 ppm each of zirconium and magnesium are included as corrosion and mass transfer inhibitors. This solution is circulated by pumps under relatively low pressure in a closed loop. In one section of the loop is a container with a graphite moderator; when the solution passes through the moderator, fission occurs and heat is generated, with a resultant temperature rise in the solution. At another section of the loop, a heat exchanger removes this heat, which serves to produce steam that, in turn, is used to drive a conventional turbine generator.

Some of the advantages offered by an LMFR are as follows: fission product poisons, which when accumulated in the fuel reduce the efficiency of reactor operation, can be removed on a continuing basis while the reactor is in operation. In a heterogeneous reactor system (e.g., the Brookhaven research reactor, already described), it is necessary to shut down the reactor to remove fuel elements poisoned by excessive fission products. This, naturally, would be undesirable in a reactor designed to supply power to a grid system. A second advantage lies in the high temperature of the steam (900° to 950°F) which an LMFR can produce. This could provide an overall plant efficiency of about 40 pct, which compares favorably with that available in most modern conventional steam plants. Third, the LMFR can be self-regulating, thus reducing the necessity for mechanical control rods to regulate the neutron intensity. As an additional economic dividend, an LMFR can be designed to *breed* its own fuel. To do this, a graphite structure known as a *blanket* would surround the core, through which a mixture of thorium and bismuth is circulated. The excess neutrons from the fissioning U^{233} atoms in the core would be captured by the thorium in the blanket, to form more U^{233}. This new U^{233} would be removed by an extraction process with molten salt, and stored for use as needed in the core. Any excess could be made available to other reactor plants, thus entailing a further cost benefit.

Design of the LMFR has now reached beyond the bench scale. Experimental test loops have been developed to determine the components that can provide the best service in handling such highly corrosive fuel at high temperature. Other loops have circulated fuel under radio-active conditions; for these experiments, the research reactor is used.

Other major research projects

In this brief review, it has been possible to present only a few of Brookhaven's many diverse scientific activities, and to describe only those major research tools of most universal use. The present permanent staff of some 1800 persons is occupied, directly or indirectly, in pushing back the frontiers of knowledge in such widely divergent fields as the use of isotopes in studies of mineral and vitamin utilization in the human body, the design of a high speed digital computer with a 12,000-word memory, the gamma-induced polymerization of vinyl resins, and the use of radio-active tracers in studying nutrient uptake by root system in plants. A new Medical Research Center, complete with 48-bed hospital, has just been completed; here, the Laboratory's physicians will have greatly improved facilities for continuing their research in the many uses of nuclear energy in medicine. This Center has its own reactor, a 1-Mw tank-type with light water-moderated and cooled fuel, and a forced air-cooled graphite reflector. Among the biological research facilities are a 10-acre field in which is centered a 2000-curie source of cobalt-60, a greenhouse where a smaller gamma source is located, and a thermal column atop the research reactor for the neutron irradiation of seeds and domant buds.

Conclusion

Today over 98 pct of Brookhaven's research can be performed on an unclassified basis, and this means that most problems can be discussed on a perfectly free basis, even with foreign visitors. It also means freedom of publication, with the widest possible dissemination of the results. In this atmosphere it is difficult to recall the restrictions of only a few years ago, when even the research reactor and its components were considered national secrets. Research must be free to prosper, especially in Brookhaven's case. As one staff member succinctly summarized it in the early days: "We're different. Hanford makes plutonium, Oak Ridge makes U^{235}, Los Alamos makes bombs. We don't make a thing—except knowledge."

With this kind of a charter, and the support of the USAEC, demonstrated by its present capital investment of about $80 millions, Brookhaven can face its future with confidence. But this confidence should, perhaps, be tempered with some humility, for in fundamental research the years ahead cannot be planned with any degree of certainty. The new fields of endeavor that will open up can only be suggested. The lines of approach to problems shift as the new discoveries are made, in all the rapidly developing areas of nuclear science and technology. The words of the brilliant English scientist Michael Faraday, spoken 100 years ago, are still most appropriate today:

"It is the great beauty of our science that advancement in it, whether in a degree great or small, instead of exhausting the subject of research, opens the doors to further and more abundant knowledge, overflowing with beauty and utility."

ADVANCES IN NUCLEAR FUEL ELEMENTS

More than 500 nuclear scientists and engineers from 22 nations gathered at Columbia University for the First International Symposium on Nuclear Fuel Elements, sponsored jointly by Columbia and Sylvania-Corning Nuclear Corp. Their conclusion: better materials will be needed before economic nuclear power becomes a fact of everyday life.

by J. J. Burke

FUEL element and recycling costs are now the major barrier to economic nuclear power. This may be stated as an unqualified conclusion of the First International Symposium on Nuclear Fuel Elements, held recently at Columbia University. Although fuel elements may be the only barrier, it can not be said that economic atom-power plants are just around the corner, because the problems still to be faced are formidable. How can fuel-recycling costs be brought down? What about the gas-cooled reactors that are receiving so much attention in Europe? What composition has the best combination of properties for use in large power reactors—natural uranium, enriched uranium, stoichiometric uranium dioxide, uranium carbide, plutonium, thorium, or ceramics? What cladding materials will find use—and what of the unclad elements? These were just a few of the questions that were discussed. Summarized below are some of the current thoughts of men who attended the conference.

Higher temperatures on the way

The outlook is for higher operating temperatures —giving better thermal efficiency—which in turn requires better materials. Solid fuels will push liquid-fueled, homogeneous types of reactors out of the picture. At higher temperatures, ceramic-type fuel elements, urania and thoria, for example, will be of key importance; they have the necessary capacity to provide slow burnup rates at the temperatures required. In tests conducted by NDA, alumina showed many excellent properties as a component of fuel elements. Non-nuclear tests by Degussa on alumina tubes showed extremely high radial heat flow in the temperature range of 1100° to 1200°C. The corrosion problem must be overcome, and two possible solutions exist: a coolant that is non-corrosive at high temperatures, or alloys that are corrosion resistant at such temperatures. Both solutions are being examined.

Gas-cooled reactors have many very intriguing advantages. First, it is possible to run them at much higher temperatures than liquid-cooled types. Second, a gas coolant has inherent advantages with respect to corrosion problems. Lastly, a completely unclad fuel element would be practical only in a gas-cooled device. The unclad element is a very bright star in an otherwise cloudy sky which surrounds fuel recycling and its attendant costs. At present, clad elements must be either mechanically stripped of their jackets or melted down, jacket and all, for chemical reprocessing, which includes separation of the jacket material. This involves a great deal of remote handling, and is richly productive of very *hot* waste materials. Recycling of unclad elements is a comparatively cheap and simple operation. On the other side of the coin, an unclad element presents certain problems in reactor operation, since a certain amount of radio-active material is bound to be picked up in the gas stream, and this must be scavenged out or other parts of the system will become hot themselves.

Certain economic factors could bring fuel element costs down appreciably in the near future. Standardization of design and mass production techniques will naturally have this effect. Although one manufacturer is already marketing a *standard* fuel element, the feeling seems to be that it is still too early to say that any one type is preferred. It is felt that the benefits of large-scale production will accrue automatically when costs are otherwise brought nearer a competitive level.

Looking still farther ahead, the direct conversion of heat to electricity by thermoelectric generators is a prospect wondrous to behold, but it is, unfortunately, still in its infancy. An opinion was expressed that solid-fueled reactors would still be used for this type of equipment. Many people think that this method of power generation will not be available until the physicists are ready to install thermonuclear machines in power plants.

Natural uranium

While natural uranium is the cheapest and least complex fuel available, and it is also relatively easy to fabricate and reprocess, there are several severe limitations on its use. There is so little fissionable U^{235} isotope in natural uranium that 150 tons are required to generate a critical mass that will sustain a chain reaction. The material has a high degree of anisotropy—upon heating it expands in two crystallographic directions and contracts in one—and as irradiation proceeds, the fission products, particularly radon and xenon gas, are trapped within the mass and cause swelling, changing the density as much as 20 to 30 pct.

Uranium oxide elements

Elements of a stoichiometric UO_2 composition appear to have a very bright future. While the oxide content tends to build up with use of certain coolants, carbon dioxide, liquid sodium, and NaK may be used without harmful effects. Zirconium may be used as a cladding material up to 700°C, aluminum up to 500°C, and beryllium and stainless up to around 500° to 600°C. Thermal conductivity is low, but this is counteracted by the high melting point, which allows the center of the element to operate near the melting point. Another advantage is that it is isotropic, which eliminates the distortion problem. It was recommended that in jacketing UO_2 elements, engineers need not worry about too close a fit as a small space between the element and jacket does not seem to make much difference on operating temperatures. Use of non-stoichiometric elements has been found to reduce thermal conductivity and, hence, increase temperature, which results in large quantities of UO_3 being given off as a gas, which causes swelling. These elements are generally produced by compaction and sintering, and it has been found that thermal conductivity is improved by 25 pct if sintering is done at 1400°C, followed by annealing 1 hr in hydrogen, and cooling in hydrogen.

Uranium—carbide elements

Due to the high cost of fissile material abroad, extraction of maximum heat from a fuel element has been an important design factor there. Much work in England has been concentrated on complex fuel element shapes which yield a higher thermal efficiency. One of the most novel of fuel element designs has been the uranium carbide fueled graphite balls developed in Germany by Degussa for the BBC-Krupp gas-cooled reactor. Fuel temperatures inside these balls are reported at 1500°C or higher. There also has been discussion of graphite balls in which the fuel is dispersed, but no reported experiments as yet. It is interesting to note that there is more uranium in UC than there is in UO_2, and the carbide has most of the oxide's advantages.

Thorium elements

At present, the principle barrier to more extended use of thorium fuel elements is lack of experience with the thorium breeding cycle. Thorium elements may operate at high temperatures, due to the fact that only one phase change occurs, an FCC-BCC transformation, and this is at 1380°C. The thorium-uranium fuel used in the sodium-graphite moderated AETR has shown good neutron economy at high energy levels. Dimensional stability is good, particularly in thoria-base ceramic elements, but the thermal properties are poor. One serious problem with this material is that the U^{232} byproduct decays rapidly, with heavy emission of high-energy gamma rays. This necessitates remote handling which is, of course, expensive.

Uranium-zirconium hydride elements

This material was developed as a completely safe type of element for reactors in schools and institutes, and it is now found in the TRIGA device. The element is homogeneous, and hydrogen is used as a moderator, this being safer to handle than beryllium. Thermal conductivity is equal to pure zirconium, but thermal shock resistance is low; however, it is adequate for a reactor such as TRIGA. Homogeneous construction minimizes dimensional instability and radiation damage. At present, the uranium used is enriched 20 pct. An added advantage of this type of element is its adaptability to a high-energy pulse-type reactor—one where the energy level shoots up in the first few milliseconds of critical operation.

It is felt that homogeneous solid fuel elements will find increasing application; the advantages of decreased grain size and minimized anisotropy must, however, be balanced against the fact that any alloying elements will absorb some neutrons.

Plate and tubular dispersion elements

Although not competitive for large, stationary power plants, plate-type dispersion elements should find considerable application in high-performance, compact reactors. They generally use an enriched fuel, and they have the advantage of a flat radial flux gradient, due to the ease of making extremely accurate additions and grading. However, the necessary powders must be pure, properly sized and, hence, are quite expensive. Tubular dispersion elements have definite advantages from a heat transfer standpoint, and they are structurally stronger, but cost is quite high.

Outlook

Dr. K. W. Davis, vice president of Bechtel Corp., and formerly director of the AEC's Reactor div., sounded the last word at the Symposium, stating that for nuclear power to be competitive, even in high-cost areas, capital cost would have to be brought down to the $225 to $250 per installed kw range, and fuel processing costs must be 2 to 2.5 mils per kw. He stated that when other costs are minimized, fabrication and fuel processing will be the critical cost factors. He emphasized that there would be no way of getting around this problem; other ideas suggested, such as operation at higher-than-rated capacity, use of heavy-water moderators, and use of nuclear superheat, would not spell the difference between competitive and non-competitive power costs. Operation at higher-than-rated capacity, while feasable on research reactors, would be completely impractical in large commercial power plants, due to the large investment in generation equipment necessary. There is no advantage in the use of heavy-water moderators at present; although research is necessary on thermal and fast breeder reactors, there will be no pressing need for them until around 1990, based on present raw material supplies.

Dr. Davis felt that, while no one type of reactor would be determined as best for all applications, the boiling water, organic cooled, and high-temperature gas reactors, in that order, would find the broadest use.

It is easy to see that, over the next few years, the advent of a nuclear power industry is going to be highly dependent on developments in nuclear metallurgy.

Editor's note: The complete proceedings of the First International Symposium on Nuclear Fuel Elements will be published in August of this year by the Rheinhold Publishing Co. Editors: H. H. Hausner and J. Schumar. It is planned to include a complete bibliography on the subject, with more than 500 literature references.

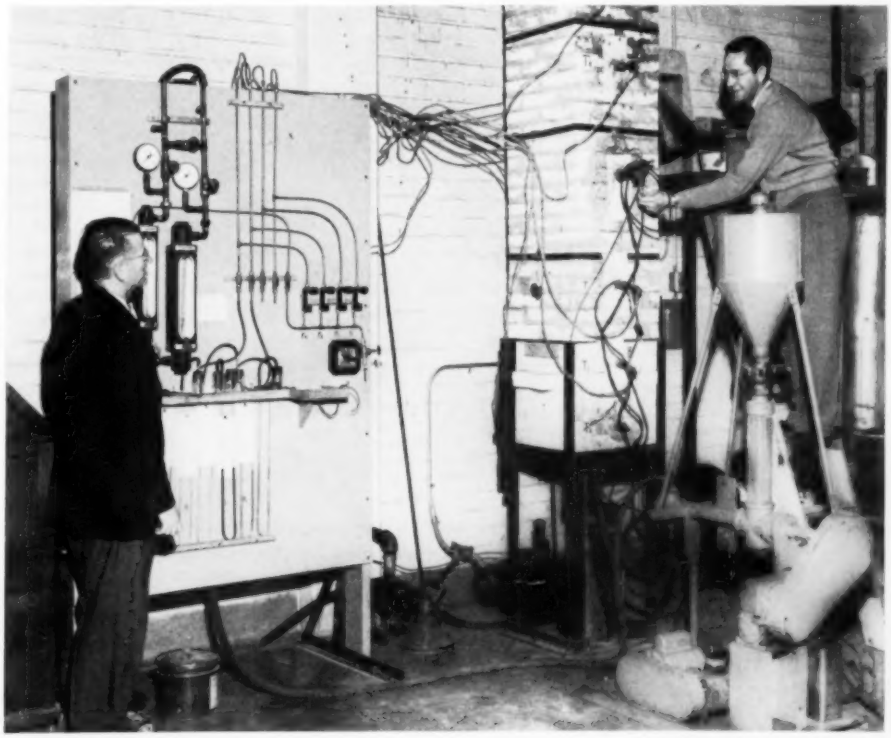
UNIVERSITY SESSION ON FLUIDIZING REACTORS

Symposium at the University of Arizona aimed at wider dissemination of data on operating use of this air-suspension roasting method.

A week-long educational program and two-day symposium on applying the fluidizing reactor to the minerals industry drew more than 100 engineers to the University of Arizona at Tucson several weeks ago.

The educational program, intended for engineers who will work closely with the reactor, attracted registrants from all sections of the US and Canada. Meeting at the College of Mines on February 23rd for a full week of intensive classwork, the engineers ploughed in with enthusiasm. Eight hours daily of lectures and laboratory work were followed by a generous helping of homework supplied by Professor Sigmund L. Smith, who directed the course. The study program was completed on Friday, and the following Monday marked the start of a symposium of technical papers covering a wide variety of operations and new ideas.

Symposium Program: Shortly after 9:00 am the program of papers was started; four during the morning session and another four following a noon break for lunch at the university.



Prof. Sigmund L. Smith (at left) adjusts controls of the FluoSolids reactor at the University of Arizona, College of Mines. At right, Fred L. Stubbs, instructor in metallurgical engineering, checks adjustments on the 4-in. FluoSolids reactor.

This article also appeared in MINING ENGINEERING.

The papers included:

□ "The Fluidizing Reactor at Hayden, Ariz." by Henry W. Franz, Kennecott Copper Corp.

□ "FluoSolids Roasting at the Anaconda Property at Weed Heights, Nev." by Henry R. Burch, The Anaconda Co.

■ "FluoSolids Roasting of Bagdad Concentrates" by Edward S. Howell, Bagdad Copper Corp.

□ "Drying of Concentrates by the Fluidizing Reactor" by George H. Roseveare, Arizona Bureau of Mines, and Charles H. Curtis, Duval Sulphur & Potash Co.

■ "FluoSolids Roasting Practice at Giant Yellowknife Gold Mines Ltd." by John M. Mortimer, Ventures Ltd. and Giant Yellowknife Gold Mines Ltd., and Robert J. C. Tait, Giant Yellowknife Gold Mines Ltd.

□ "The Relative Merits of Fluidizing Reactors as Compared to Fixed Bed Reactors in Metallurgical Processing" by Joseph F. Skelly, The M. W. Kellogg Co.

□ "FluoSolids Two-Stage Roasting" by Donald MacAskill, Dorr-Oliver Inc.

□ "Possible Smelting in a Fluidizing Reactor" by Sigmund L. Smith and Fred L. Stubbs, University of Arizona.

Following the presentations, a group of panel experts were assembled for a round-table discussion and question period which completed the session.

On March 3rd, the day after the symposium, the group enjoyed a field trip at the nearby Kennecott Copper Corp. facilities at Hayden, Ariz. The tour, guided by plant engineers, included the new $30-million Hayden smelter, the fluidizing reactor, and the reduction plant.

Papers Available: Certain of the papers presented at the symposium dealt primarily with operating practice. Data from those papers marked ■ in list above are given in condensed form in the following pages. The paper on *The Fluidizing Reactor at Hayden, Ariz.*, by Henry W. Franz will be given in the July issue of *Journal of Metals*.

All the papers presented and formal discussion will be available through a proceedings volume which the university is now in the process of preparing. Interested readers should contact Professor Sigmund L. Smith, College of Mines, University of Arizona, Tucson, Ariz. The volume will cost $4.

AT BAGDAD

Overall Process: To convert the copper in mill concentrates to cathode copper by electrolysis necessitates a high copper, low iron, soluble calcine. Early attempts at Bagdad to produce such a calcine failed through lack of a suitable roaster and inability to closely control reaction temperatures. Availability of the FluoSolids roaster plus advances in temperature control equipment made further tests worthwhile.

Reactor Application: A pilot plant was designed to treat 5 tpd of concentrate, containing about 26 pct Cu, 26 pct Fe, and 31 pct S. The roasting circuit had slurry mixing tanks, a Com-Bin feeder for filter cake, FluoSolids roaster and component parts, cyclone, scrubber, SO_2 stripper, exhaust fan and stack, calcine quench circuit, scrubber solution circulating equipment, fluidizing blower, and reactor control panel.

Lined with brick, the reactor was 5 ft ID and 16½ ft high. A Foxboro M40 Stabilog and Dynalog Multi-Record provided temperature control. Air volumes were manually controlled by a Foxboro unit which gave a 24-hr record. Three thermocouples were located within the fluidized bed area: one in the top of the reactor freeboard, one in the cyclone intake, and one in the scrubber outlet. Excessive temperatures were controlled by the introduction of cooling water into the reactor freeboard by Stabilog control. Gas pressure taps were located in the reactor windbox, fluidized bed area, freeboard, cyclone, and scrubber. Static head of fluidized material above the bed pressure tap was the guide for maintaining bed depth.

Top overflow calcine discharge was abandoned after difficulty, and bottom discharge was installed at constriction plate level.

Tests up to this time strongly indicated the need for an increase in the space rate (then 0.75 fps) to maintain fluidity. Leaching and electrolytic circuits were designed to accommodate a 5-tpd reactor feed, and it was therefore necessary to decrease the bed cross-sectional area by half in order to double the space rate while maintaining the same fluidizing air volume.

Table I. Roaster Feed Composition and Solubilities Following Roasting at Bagdad

	Date	Cu, Pct	Fe, Pct	S, Pct	Insol., Pct	H_2O-Sol. Cu, Pct	H_2SO_4-Sol. Cu, Pct	H_2O-Sol. Fe, Pct	H_2SO_4-Sol. Fe, Pct
Lowest Cu	6-10-57	15.93	33.70	34.97	13.14	95.86	99.01	1.94	2.37
Highest Cu	11-19-56	38.63	17.80	26.24	12.14	79.46	94.77	2.99	3.96
Lowest Fe	11-19-56	38.63	17.80	26.24	12.14	79.46	94.77	2.99	3.96
Highest Fe	6-10-57	15.93	33.70	34.97	13.14	95.86	99.01	1.94	2.37
Lowest S	10-7-56	22.52	24.10	18.56	24.42	76.12	95.12	0.96	1.56
Highest S	6-9-57	17.22	30.10	35.51	13.52	95.36	98.60	2.08	2.42

Table II. Solubilities at Varying Roast Temperatures at Bagdad

Roast Temperature, °F	Cu, Pct	Fe, Pct	S, Pct	Insoluble, Pct	H_2O-Sol. Cu, Pct	H_2SO_4-Sol. Cu, Pct	H_2O-Sol. Fe, Pct	H_2SO_4-Sol. Fe, Pct
1261	27.75	23.43	28.80	14.21	94.23	98.13	2.94	3.74
1275	27.27	23.68	29.64	14.58	94.60	98.42	2.86	3.60
1300	27.78	23.10	29.16	16.38	79.51	95.91	1.48	2.14

The increase to 1.50-fps space rate resulted in an increase of solids carryover to the cyclone and scrubber circuit, but it also eliminated progressive loss of fluidity within the reactor bed during roasting. Solids recovered by the cyclone were about 24 pct of the reactor feed.

The final solution to the problem of introducing slurry feed was a slurry gun inserted through the top center of the reactor shell. This placed the end of the gun barrel within 1 in. of the inside surface of the top castable lining.

Cooling water, which had been added through the wall of the reactor and into the freeboard, was connected to the new slurry gun and served as a continual liquid purge. A small flow of cooling air was passed through the cooling jacket and vented to the atmosphere. In addition, a small air flow entered the gun barrel to encourage the cooling water purge. Concentrate slurry feed leaving the gun fell through the hot reactor freeboard and into the fluidized bed below. This feeding technique proved very satisfactory. All concentrate slurry entering the slurry feed tank was passed through an 8-mesh screening box to remove tramp material which would plug the feed gun. Concentrate slurry containing 76 pct solids was advanced to the feed gun by a small diaphragm pump with a variable-speed Reeves drive. Feed input to the reactor seldom exceeded 2 qt per min and proper control was important.

Increases in the space rate, plus a suitable feeding method, placed the operation on a continuous 24-hr basis and permitted a test program to begin.

Rarely did two consecutive test batches of concentrates contain the same component percentages. Concentrates varying from a low of 15.93 pct to a high of 38.63 pct Cu were satisfactorily roasted by changing fluidizing air volumes and feed rates.

Table I shows the minimum and maximum copper, iron, sulfur, and insolubles percentages of the roaster feed as well as the resulting solubilities in water and dilute sulfuric acid.

Percentage of water-soluble copper in the calcine was affected to a larger extent by the copper:sulfur ratio of the concentrate feed than was the percentage of H_2SO_4-soluble copper. Concentrates containing progressively less sulfur than copper would produce a calcine containing progressively less water-soluble copper while maintaining a + 95-pct H_2SO_4-soluble copper. Calcines produced from high sulfur and lower copper concentrates would normally yield a water-soluble copper content of 90 to 95 pct and an H_2SO_4-soluble content of 97 to 98 pct.

Roasting temperature controlled copper and iron solubilities. Temperatures of 1300°F and higher, while decreasing iron solubilities, would greatly lower water-soluble copper and also be reflected in the percent of total soluble copper.

Roasting temperatures from 1270° to 1280°F were considered best for production of a high-water, H_2SO_4-soluble copper calcine while also holding iron solubility to a minimum. See Table II.

Table III represents screen analysis of the concentrate feed, calcine, and leached residue produced for a three-day period, and includes data on copper and iron solubilities of the calcine.

Subjecting the copper sulfide to copper sulfating roast introduces bed conditions very different from the oxidation roast of chalcopyrite or pyrite.

The relatively large percentage of copper sulfate within the fluid bed demands sufficient space rate for satisfactory fluidity within the bed. As previously mentioned, insufficient space can result in complete loss of bed fluidity. Loss of power, equipment failure, etc., may at times result in forced or intentional defluidizations. Loss of reactor time affects the entire operation as the leach circuit and tankhouse are dependent upon calcine production.

Inability to refluidize the dormant bed will require partial or complete removal of the bed material. Complete removal of the defluidized bed must be followed by a preheating and bedding operation before normal operation can resume.

Copper sulfate, with a melting temperature of 392°F, is the major bed preparation problem. This material imparts a *tacky* condition to the calcine particles and lack of sufficient movement permits these particles to cling together. The bed can be refluidized only if the shocking force of the refluidizing air is strong enough to break the calcine bond.

Addition of ferric oxide tail material to the fluid bed results in a coating of the tacky calcine particles and was found fairly successful in permitting refluidization.

The most successful bed preparation technique involved oxidation of surface copper sulfate to copper oxide, thereby destroying the tacky coating. This was accomplished during a period of no feed entry, with the bed fluid, and while temperature was maintained by injecting fuel oil through a bed oil gun. A 2-hr oxidation period was found long enough for a 30 pct copper concentrate feed, producing a 90 to 94 pct water-soluble copper calcine.

Table III. Screen Analysis, April 12-14, 1957

Concentrate*

Screen Size	Pct Retained	Cumulative
+48	1.20	
+65	6.35	7.55
+100	11.20	18.75
+150	13.00	31.75
+200	10.40	42.15
−200	57.85	100.00

* Cu, 27.32 pct; Fe, 24.87 pct; S, 29.34 pct; insoluble, 13.71 pct.

Calcine**

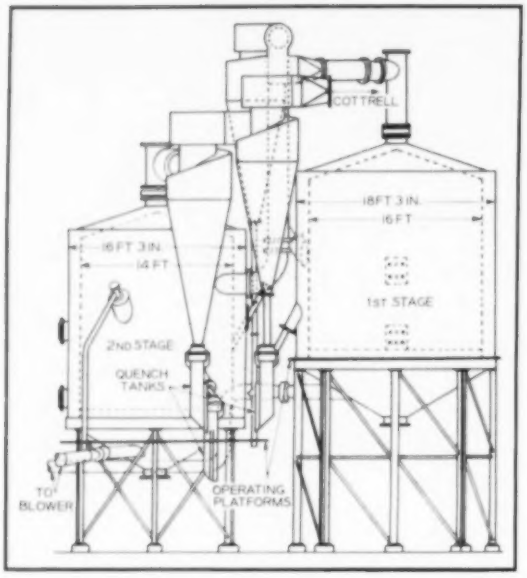
Screen Size	Pct Retained	Cumulative
+48	27.90	
+65	17.80	45.70
+100	21.10	66.80
+150	20.10	86.90
+200	9.10	96.00
−200	4.00	100.00

** Total Cu, 22.97 pct; H_2O-insoluble Cu, 94.48 pct; H_2SO_4-insoluble Cu, 98.55 pct; total Fe, 20.23 pct; H_2O-insoluble Fe, 2.47 pct; H_2SO_4-insoluble Fe, 3.26 pct.

Leached Residue***

Screen Size	Pct Retained	Cumulative
+48	1.20	
+65	6.20	7.40
+100	33.00	40.40
+150	27.80	68.20
+200	13.30	81.50
−200	18.50	100.00

*** Cu, 1.04 pct; Fe, 48.87 pct (calculated); insoluble, 27.76 pct (calculated).



Giant Yellowknife's No. 2 Dorrco roaster.

AT YELLOWKNIFE

Overall Process: Ore at Giant Yellowknife is complex and refractory to simple amalgamation and direct cyanidation. Improved gold recoveries have come through autogenous roasting of concentrates and cyanidation of the calcines.

To summarize the treatment process, the ore is crushed, ground, classified, and floated to produce a bulk gold concentrate. The flotation tailings are cyanided for additional recovery. The flotation concentrates are roasted. Pyro-metallurgical oxidation of the compact metallic sulfide crystals to relatively porous oxides leaves the gold in the calcine amenable to cyanidation. The calcine is treated in a separate leaching circuit. Leached residues are retreated in a rotary kiln and the product combined with the flotation tailings and again cyanided. The cyanide circuits are conventional.

Reactor Application: Giant first used an Edwards type, duplex flat-hearthed roaster in January 1949. Shortly afterward news of good results at other gold operations prompted the company to install a FluoSolids reactor when mill capacity was expanded.

Modifications of the first such roaster tried were only partly successful and the company was again faced with the need for more roaster capacity to handle large ore reserves, which were mainly of the more refractory type. The No. 2 Dorrco roaster shown in an accompanying illustration was put into production in November 1958.

At a milling rate of 960 tpd, the new roaster makes noticeably less dust than was made at 750 tpd with the two old roasters.

The roaster's 16-ft diam first-stage compartment is set about 5 ft higher than the second stage. Air, supplied by a 3700-cfm blower, enters the first stage through 292 club-head tuyeres. Air to the 14-ft diam second stage is supplied by a 2100-cfm blower and enters through 216 tuyeres. Bed overflow of both stages is 5 ft above the tuyeres.

Four bed thermocouples are provided for each stage and spray water is adjusted manually using gate valves on the rotameters. The thermocouples are connected to two recorders so that temperatures can be read even if one unit is out of order.

Roaster feed rates have been held at about 150 to 155 tpd since Nov. 28, 1958. Conclusions cannot be drawn on results so far, but the figures below show approximate roasting conditions after the most recent temperature adjustment:

Feed rate, dry solids	157 tpd
Stage 1 air rate	3350 cfm
Stage 2 air rate	1660 cfm
Stage 1 temperatures	1000°F, bed; 920°F, freeboard
Stage 2 temperatures	1050°F, bed; 1035°F, freeboard
Slurry density, solids	78 pct
Spray water, Stage 1	3 gpm
Spray water, Stage 2	—1 gpm

Cyanide extractions under these conditions are very encouraging. They averaged well over 80 pct for the first two weeks of this year. Although the operators note that another 50° drop in temperature in each stage would simulate closely their ideal laboratory roast, further temperature reductions will be approached with extreme caution.

Calculated space velocity of the second stage compartment is roughly 0.6 fps, which may be too low for effective operation. Product examination shows a high degree of classification is taking place in the bed. Only the coarsest material overflows, and probably 70 pct of total product is being discharged from the first cyclone. It is probable that a false bottom has formed, and that only about half the original area is active.

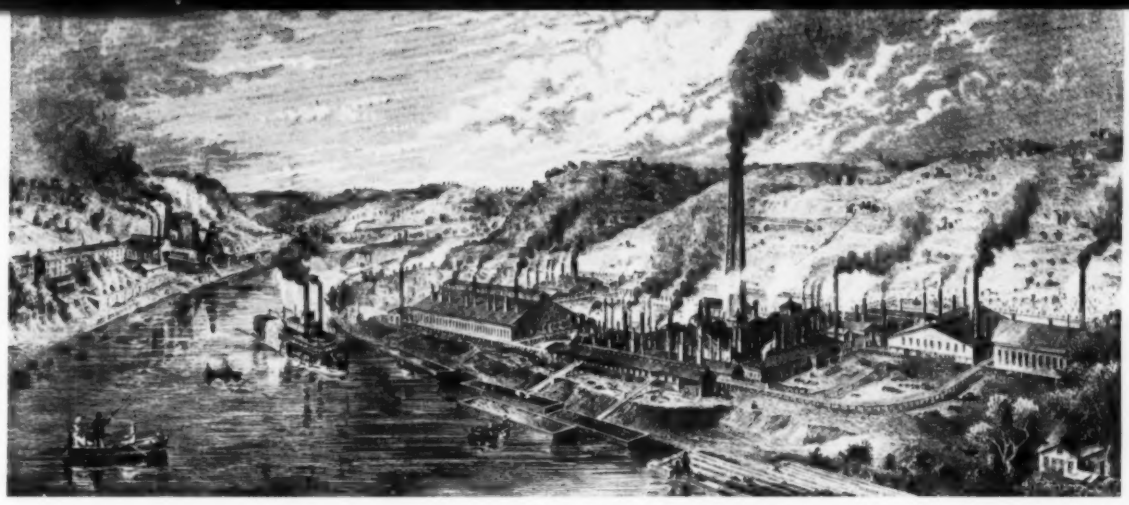
About half the roaster is cool to the touch, and the active roasting zone appears to extend about 90° around the shell, on either side of the transfer point. This condition is probably aggravated by the location of the bed overflow pipe, which is less than 90° removed from the feed entry point. The operators believe the diameter of the second stage should be reduced and the overflow pipe and quench tank moved to a point directly opposite the feed entry.

Most of the roasting seems to be taking place in the freeboard of the second stage. Because second stage temperature appears critical to extraction, the freeboard temperature must be carefully watched. Stage 1 bed condition seems to be excellent.

Dust losses appear to be moderate and probably do not exceed 5 pct.

Oxygen content of the first stage flue gas is apparently a critical quantity. During a two-week run with first stage temperature held at 1050°F and the second stage at 1100°F, there were suddenly three days of very poor extraction. Feed analysis had remained consistent and there were no abnormal variations. The only difference appeared to be that oxygen content of Stage 1 gas was recorded as trace for the three troublesome days. Prior to this it had been running 0.3 to 0.5 pct O_2.

While it is much too early to draw any positive conclusions, it is quite possible that optimum extraction may mean relatively short bed life. If so, the relative economics of interrupted production, and good extraction, must be weighed against one another.



American Iron Works of Jones & Laughlins (Pittsburgh), in the 1880's: from an old etching.

STEELMAKING / U.S.A.

Part II of a four-part series on the history of steelmaking in the US, points out the inadequate safety and living conditions that existed in steel mills at the turn of the Century. Also defined are furnace and process developments.

by Leo F. Reinartz

OPERATIONS in steel plants today are highly mechanized. Men work in light, clean, orderly melting shops, making it difficult for oldtimers to convince young men that primitive, hazardous conditions existed in steel plants at the turn of the century. Working conditions then were very poor as compared to present day standards. In small plants especially, sanitary, locker, and washroom facilities, first-aid practices and stations were unknown. Accidents were frequent and severe.

Workers had a fatalistic attitude toward getting hurt. He who had an accident was looked upon as a hero. A dirty bandanna often served as a bandage. Infections were frequent.

Electric cranes were in their infancy and broke down often. Cables had not as yet replaced chains. Pig iron and scrap iron were loaded by hand in the stockyard, and stockyard locomotives were unknown; mules served as the usual motive power. It was not unusual to see recorded a delay of ½ hr in charging a furnace because of a balky mule.

Furnace operations

A few plants had primitive **charging machines**, but most furnaces were charged by placing scrap or pig iron on the paddle of a long peel, which rested on a bar across the furnace door opening. Laborers at the handle end of the peel, using the bar as a fulcrum, would heave the material into the furnace by a down and sideward motion of the peel handle. In time they became expert in placing these materials in the furnace, but it was hard, hot work, and a long time was required for charging. Cold charges of 25 tons required more than 12 hr for melting and refining the steel.

Ports, doors, and frames were not water cooled. The charging and working area in front of the furnace was covered with steel plates. They were hot and often warped by the intense heat of the uninsulated checker chambers directly below. In the summer, working conditions on the charging floor were almost unbearable.

Silica refractories were of poor quality. Because of this, and the inadequate training of furnace men in fuel control and furnace operations, roofs, front and back walls, and ends burned out rapidly. **Dolomite machines** were unknown; consequently, furnace banks and hearths were fettled with dolomite by the use of hand shovels.

The **round system** required six or more men. Each man took a shovelful of dolomite and, in his turn, deposited it on the back wall and bank by a dexterous forward swing and twist of the shovel. The upward swing of the shovel partially protected his face from the searing heat of the furnace coming out through the wide-open door. Considerable skill and stamina were required to do this job properly.

Reverse valves, usually of the cast-iron butterfly type, were located below the charging floor. They were operated by long levers on the charging floor level. When they became warped, because of heat and abuse, great strength and skill were required to reverse them.

Furnace operations were difficult. The quality and quantity of producer gas coming from irregularly stoked, hand-operated gas producers was uncertain and unreliable. Furnace linings and ports were quickly burned out.

Poor bottom and side-wall refractories, indifferent and inexperienced crews, as well as irregular re-

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versals, caused many breakouts. Molten metal ran out through the brickwork onto the floor, through the back wall into the pit, or through the end chill boxes of the furnace into the slag pockets. These happenings were often accompanied by explosions and fire. Because of the lack of floor cranes, breakouts on the floor were responsible for numerous delays and long hours of backbreaking work to clean up the mess.

Topping: Early furnaces were built on ground level to reduce construction costs. As a result, tapping pits were below floor level. Ladle stands under the furnace tapping spouts were unknown. When a heat was ready (which was indicated by beating on a large steel plate, blowing a whistle or ringing a bell), the ladle was brought by the ladle crane to the furnace and lowered into the pit under the spout.

At times, owing to faulty refractory materials or to inefficient closing of the taphole after a heat had been tapped, the next heat might tap itself before a ladle could be placed under the spout. It was an awsome and nerve-racking sight for the superintendent to see an entire heat of steel go down into a deep ladle pit. Usually such an event meant a furnace delay of several days, together with grueling, dangerous work cooling and removing the chunk of steel.

No oxygen was available in those days to cut up such scrap. Often the chunks could not be salvaged because of their size and shape. In these cases, a hole was dug in the ground and the piece was jacked off the car into the hole to rest there until skull crackers or the oxygen torch (at a later date) made salvage economical. During such periods, open-hearth furnaces could be operated almost entirely on skull and breakout scrap.

Hazards did not stop there. Stopper rod and nozzle assemblies were tricky. If they were not properly made up, handled, and dried carefully, or if the heat was on the cold side, a *running stopper* might be caused by rod or nozzle failure. This would mess up molds, stools, cars, and tracks. It was dangerous to go near the ladle. The craneman, at considerable discomfort and danger to himself, moved the ladle from mold to mold, accompanied by a geyser of sparks and flame, as best he could. The quality of a heat produced by long hours of careful melting and refining could be ruined in minutes by a running stopper or other pit mishap.

Because of the lack of dynamite, jack-hammers, conveyors, bulldozers, and other modern mechanical facilities, and because of the location of slag pockets and checker chambers below ground level, furnace repairs were long, tedious, and relatively costly. Furnace availability, therefore, was very low.

Only a portion of the trials and tribulations faced by workers, supervisors, and management from 1888 (when basic furnaces began to operate at Homestead, Pa.) until about 1910, have been enumerated. It will now be desirable to relate how Mother Necessity, over a period of many years, has increased production in the open-hearth shops, improved quality, decreased costs, and immeasurably improved the lot of the steelworker in the melt shops.

Improvement through invention

Samuel T. Wellman invented the **electric charging machine** in 1887. However, records indicate that the first electric charging machine was installed in the Lakeside plant of the Otis Steel Co. in 1894. This invention decreased the number of laborers in the shop, greatly speeded charging, increased production, and decreased costs. A number of years elapsed before all open-hearth shops adopted this labor and time-saving machine.

In 1895 Wellman invented another great boon to steel management, the **electric magnet**, which could load pig and scrap iron into charging pans rapidly and cheaply. Again, this invention eliminated much hard labor.

During the 1890 decade, **silica brick** manufacture for open-hearth roofs, side walls, and end walls was started. About this time it became a regular practice to import Austrian and Grecian magnesites for making basic furnace bottoms and tapholes, respectively.

Prior to 1900, open-hearth doors and frames were steel castings. The doors were lined with firebrick. During the 1900 to 1910 decade, crude **water-cooled doors** and, later on, **water-cooled frames** came into use in some of the large steel shops. The water-cooled doors and frames as they exist today came into use prior to 1915. By 1920 they had become standard in most open-hearth shops.

Reversing valves on open-hearth furnaces caused much trouble for many years. They warped, leaked, maintenance was high, and because of many turns in gas or air direction, they restricted draft and thus furnace production. Prior to 1920, reversing valves were of many sizes, makes, and shapes. In the fall of 1915, the first **straight-line gas and air valves** were installed on an open-hearth furnace by Maryland Steel Co., Sparrows Point, Md., followed early in 1916 by a similar installation at the South works of Illinois Steel Co., South Chicago.

This invention marked a great advance in furnace design and performance because an improved straight-line flue system was made possible, cutting out tortuous routes for air, fuel and waste gases. As time went on, the design was improved and this type of valve became standard in practically all open-hearth shops.

The only exception appears to be the Isley control system. The first of which was installed in 1924 on a small open-hearth furnace in Worcester, Mass. The initial installation on a large open-hearth furnace was made in a middle eastern plant in 1925. The setup required no valves in any of the flues to the stack, and the design assured adequate draft at all stages of the heat. Waste-heat boilers cannot easily be applied to such a design. Air pollution hazards are somewhat accentuated by the low stack or stacks.

These innovations, as they appeared on the scene many years ago, helped to lift the burden of hard, hot, manual work from furnace crews.

Hot metal

It is not clear just when hot metal was first used in basic open-hearth furnaces.

The hot metal mixer, invented by William R. Jones (AIME member, 1875), was first used in bessemer steel manufacture at the Edgar Thomson works of the Carnegie Company, Braddock, Pa., in 1889. It is known that such large steel companies as Carnegie, Phipps & Co. Ltd., Pennsylvania Steel,

and Jones & Laughlin used hot metal from mixers prior to 1900.

Mixers increased in size until at some shops today they can hold 1500 tons of hot metal. However, they have their weaknesses. Various casts of molten iron are not truly mixed. The vessels are difficult and costly to maintain. Hot metal is transferred from the blast furnace to the open-hearth department in small, open-top ladle cars. The metal cools considerably before it is dumped into the mixer, where it is difficult to maintain the temperature. Modern vessels, therefore, are heated with gas.

The first mixer-type hot-metal car was put into service by Jones & Laughlin at Eliza furnace, Pittsburgh, early in 1916. Its rated capacity was 90 tons. Everyone concerned was afraid that the metal might freeze in the ladle. The first ladle, therefore, was made of three steel castings bolted together for swift dismantling if a freeze did occur.

This submarine-shaped ladle with a small opening on top holds heat very well without the use of a mixer. It can be revolved on its horizontal axis to pour hot metal into an open-hearth transfer ladle which rests on a scale. Present day mixer cars hold up to 200 tons. Improvement in the uniformity of analysis and temperature of hot metal cast from blast furnaces has increased the trend in recent years toward mixer cars only.

Furnace developments

Tilting Furnace: Harry H. Campbell built six 50-ton tilting open-hearth furnaces at Steelton, Pa., in 1889. A mixer was used in connection with these furnaces. The furnaces were hydraulically tilted. Fuel could be kept in the furnace when the latter was in a tilted position. A high percentage of molten iron was charged.

This process was advantageous because the first slag could be removed easily and a new slag formed. Tons per hour was high. The taphole was simple, and back wall and bottom maintenance easy.

In 1899, Talbot tilting furnaces were installed at the Penncoyd Iron Works, Philadelphia. The Talbot method left some metal and slag from a preceding heat in the furnace. Burnt lime, scale, or iron ore was then charged. Next, hot metal was then added. Reactions were rapid and violent, and tons per hour was high. There were several serious disadvantages: large quantities of scrap iron (which often was very cheap) could not be used; furnace maintenance and fuel costs were high; metal losses were excessive; and quality of steel was questionable. Also investment costs were high.

A number of tilting furnaces were built during the next 20 years; 10 Talbot furnaces were operating in the U. S. in 1906.

Duplex process: The duplex process—acid bessemer and basic open-hearth furnaces—was started at Tennessee Coal & Iron Co., Birmingham, in 1904. A number of plants, especially those with high capacities for hot metal, followed this example.

Stationary furnaces: During the past 20 years or more, many of the remaining tilting furnaces have been converted to the stationary type, except in the southeast, where high-phosphorus pig iron is still being refined.

From 1870 to 1900, the size of furnaces increased slowly. Originally, furnaces held 5 to 15 tons. By 1900, open-hearth furnaces were tapping 35-ton to 65-ton heats. In that year, 75-ton furnaces were designed.

Between 1907 and 1908, the open-hearth tonnage exceeded bessemer steel production for the first time. Open-hearth production increased rapidly, especially during World War I (233 new furnaces were built between 1915 and 1918, more than doubling the 1909 tonnage).

For a number of years after the War ended, the demands of a peacetime economy were less than required to utilize this excess steel capacity. But in time the economy caught up and new capacity figures were set.

By 1925, new stationary furnaces were tapping 150-ton heats, and some prominent steel men were questioning the quality of steel made from such large furnaces.

Almost from the beginning, tilting furnaces had greater capacities than stationary ones. By 1928, these capacities had risen to 300 tons. In October 1925, Ben Talbot, developer of a continuous process for making open-hearth steel, predicted that furnaces of 400 to 500-ton capacity would be built some day.

Despite the depression years in the 1930's, a steady advance was made in improvements in steel manufacture. Progressive managements took this opportunity to enlarge capacities of existing older furnaces to 150 or 200 tons and to install new auxiliary equipment.

During this period the use of increased tonnages of steel for sheet manufacture was accelerated by the installation in many steel plants of continuous strip-rolling mills, first operated by Armco Steel Corp., at Ashland, Ky., in the early 1920's. This process greatly increased tons-per-hour rolled, radically decreased costs, and improved surface quality. As a result, it now became possible for American workmen to own high-quality automobiles, household appliances, radios, and other articles made of steel.

World War II upset this trend for a number of years. During that period the demand for steel for war purposes was tremendous, especially for plates, sheets, and strip. In addition, thousands of tons had to be sent to America's allies.

Thus, more and larger furnaces—up to 250 tons in capacity—were built. Fuel efficiencies and the skill of workers increased. Alloy steels, formerly made only in small electric-melting furnaces, were produced satisfactorily in large open-hearth furnaces. Low-alloy, high-strength steels conserved strategic materials and helped win the war.

By the end of 1945, the last year of World War II, steel capacity in the United States had risen to 91,000,000 net tons. Despite greatly increased capital installation costs, the capacity of new furnaces continued to increase during and after World War II until, in 1958, a number of open-hearth furnaces were tapping heats of 300 to 350 tons. Republic Steel Corp. tapped up to 425 tons into a single ladle in its Cleveland plant. National Steel Corp., at Weirton, W. Va., tapped 500-ton heats into two ladles through a bifurcated spout. The latest furnace has a capacity of more than 600 tons.

Because of pit, crane, and runway limitations, some companies, notably Bethlehem Steel and U. S.

Steel Corp., have enlarged hearths of existing furnaces to capacities of 300 to 350 tons and are tapping these heats through bifurcated spouts into two ladles. Tons per hour of such converted furnaces is reported to be 25 to 40 pct higher than it was before the change was made.

Waste-heat boilers

In 1910, the first waste-heat boilers were installed on a 65-ton open-hearth furnace in the South Chicago works of the Illinois Steel Co. These were Heine water-tube boilers. As time went on and plant steam requirements increased, especially after fuel oil began to be used for combustion, waste-heat boilers were installed on many new open-hearth furnaces. In the early years, probably owing to draft fan limitations, steam at times was made at the expense of furnace production. In modern shops, oversized draft fans prevent this waste.

Oxygen in steelmaking

Oxygen is reported to have been first used to open tapholes in 1906. Because of its high cost, the adoption of this labor-saving commodity was slow. Today, however, an open-hearth shop, with management's accent on minimizing delay and increasing efficiency, could not function properly without the use of oxygen. It is used for preparation of scrap, maintenance work in the shop and on the open-hearth floor, as well as for tapping and teeming heats of steel. It is now customary to pipe gaseous oxygen to all parts of an open-hearth shop.

Oxygen may be injected through wicket holes in charging doors at a rate of 15,000 cu ft per hr or more to melt down scrap iron or, later in the heat, to reduce the carbon content of the molten metal quickly. Such a procedure increases tons per hour, reduces the use of expensive feed ore, and improves quality.

During recent years in some shops, oxygen has been successfully injected with the fuel into the hearth through specially designed end burners. This practice shortens the flame and increases its temperature, thus speeding up the melting rate.

In a few plants, oxygen has been injected into the furnace through permanently located auxiliary lances in each of the four corners of the furnace hearth. Such an installation is helpful in increasing production, especially in furnaces using low-pressure natural gas as a fuel. An overall improvement of 10 to 15 pct in tons per hour is possible when oxygen is injected in this way.

Prior to the 1957-58 recession, several operators had experimentally installed an oxygen lance extending down into an open-hearth furnace near the center of the roof. Such a lance helps to speed up melting of the charge without floor delays and to reduce the carbon in the metal bath. Fantastic increases in production, ranging up to 40 pct at some plants, accompanied by an increase in refractory cost of about 10 pct, have been reported.

Experiments have been made whereby hot metal, as it comes from the blast furnace, is blown with oxygen coming from lances located in the bottom of the furnace trough. The object is to reduce the silicon content of the metal. The hazards are: uncertain analysis, high temperatures, and difficulty in handling the resultant siliceous slag.

In other shops, attempts are being made to remove all the silicon and at least part of the carbon from hot metal. High-pressure oxygen is blown onto the metal in the open-hearth transfer ladle before the metal is poured into the open-hearth furnace. This practice increases metal temperature and eliminates considerable silica from the charge. Furnace additions of limestone can be reduced. Flushing operation is unnecessary, and tons per hour may be considerably increased.

Electric cranes

The first crane driven by electric motor appears to have been built in 1881. It had a single motor supplying power to various motions through a square shaft. From that time, electric motors have been used in steel plant work and for crane services to an increasing extent. It is believed that the first crane having a separate motor for each motion was built in 1889. Thereafter, a number of electric cranes were built for iron and steel companies.

Prior to 1891, electric cranes had been installed at the plants of Wellman Iron & Steel Co., Thurlow, Pa.; Jones & Laughlin Steel Corp., Pittsburgh; Carnegie, Phipps & Company's Homestead works, Munhall, Pa.; the Johnson Co. Rolling Mills, Johnstown, Pa.; Central Iron Works, Harrisburg, Pa.; and Penn Steel Castings & Machine Co., Chester, Pa.

Some of these cranes may have been used in open-hearth pits as ladle cranes. However, the first reference to a crane actually being designated as a ladle crane for open-hearth pit work was a 60/15-ton 58-ft 8-in. span ladle crane built for the Homestead works in 1897.

The first double-drum ladle crane similar to the basic design of today was built in 1903 for the Alan Wood Steel Co., Conshohocken, Pa. It was an 80/25-ton, 55-ft 2-in. span crane. Today, 4-girder, 500/125-ton ladle cranes have been installed in some of the most recently built shops.

Electric charging

Manpower began to give way to electric charging machines in the early 1890's. It is known that a 5-ton, 3-motor charging machine was built for the Edgar Thomson Steel Works, Braddock, Pa., in 1893. A 7-ton floor-type charger was installed at the Sharon Steel Co., Farrell, Pa., in 1900.

In the next few years, electric charging machines were installed in all open-hearth shops. Charging time was greatly decreased, delays reduced, and tons per hour greatly increased.

It must not be thought that these machines solved all the steel operator's delay problems. The early electric motors, cranes, and chargers were crude, slow, and often inefficient. Breakdowns were frequent and usually came at inopportune times. Electrical and mechanical crews were poorly trained, or not trained at all. Repairs by trial and error were the order of the day.

Breakdowns of ladle cranes were particularly serious. Large **skulls** often were formed in the ladle. Running stoppers were common occurrences. At times, entire heats of steel froze completely in the ladle as a result of a long delay, making it necessary to dig out the ladle brick laboriously before the chunk could be dumped from the ladle. It was customary to jack such masses of steel from railroad flatcars and bury them in the plant yard.

(Next month: furnace fuels, the upward spiral of the steel industry, and the contribution of AIME.)

NITROGEN IN STEELS

With the improvement of existing steelmaking processes and the development of new ones, a prime factor has been nitrogen content of the steel produced. This paper reviews the whole spectrum of steelmaking and nitrogen.

by Karl G. Speith and Hans vom Ende

Among the elements accompanying iron, nitrogen holds a special position in the production of steel. Its content is a co-acting factor, influencing technological properties and, hence, the possible application of the steel. Up to the present, a steel entirely free from nitrogen and made on a large production scale is not available. The nitrogen dissolved in steel comes from the materials charged, i.e., scrap and pig iron which are always nitrogen-bearing, and the amount of nitrogen present is also determined by the process applied. The last-mentioned factor is of particular importance for the steels produced by the pneumatic processes.

Solubility of nitrogen

The first investigations of basic importance on the solubility of nitrogen in iron and steel were published by A. Sieverts.[1] Nitrogen is dissolved in iron in its atomic state. The solubility of nitrogen finds its mathematical expression in the so-called *square root law*,

$$K = \frac{[N]}{\sqrt{p_{N_2}}} \qquad [1]$$

wherein [N] = nitrogen dissolved in iron in wt pct. The maximum dissolving power of iron melts for nitrogen, as a function of temperature, is indicated in Fig. 1 according to the results found by J. Chipman and D. W. Murphy.[2] Somewhat higher values, however, have been found by Th. Kootz.[3] According to his investigations, the saturation values of the iron melts with a nitrogen pressure of 1 atm amount to 0.0445 pct N at a temperature of 1560°C, to 0.0475 pct N at 1665°C, and to 0.0510 pct N at 1760°C. These values are also included in Fig. 1. Assuming the existence of equal external conditions, for instance, time of contact, contact area, and diameter of bubbles, the rate of nitrogen absorption at a given temperature will be proportionate to the difference between the nitrogen content present and the saturation content. The solubility will be lowered by increasing carbon and phosphorus contents. This is of importance for the assessment of the nitrogen absorption of pig iron.

In the production of steels on a large scale, the solubility limit for nitrogen will not be reached, since the nitrogen absorption proceeds very slowly, even in the presence of a large amount of nitrogen introduced by the air, fuel gases, the blast, or other gaseous nitrogen carriers. The reason for this lies in the fact that nitrogen is present in these gases or gas mixtures in its molecular form. With the nitrogen in its atomic state, however, a much faster absorption of nitrogen will be possible. It is known that extensive use is made of this fact in increasing the nitrogen content of steel melts by ammonia or calcium cyanamide, as well as in the hardening of steels by nitriding.

There is, on the other hand, the possibility of removing the nitrogen already dissolved in the steel under certain conditions. Vigorous boiling of the bath in the open-hearth process, as well as removal of the carbon by gaseous refining agents in the pneumatic processes and in numerous special processes which have been developed quite recently, leads to a decrease of the nitrogen content within the melt. This decrease is of different magnitude in different cases, since during the course of the production process—and this applies particularly to pneumatic processes—besides the nitrogen-removing effects, there are also effects resulting in nitrogen absorption. In the end, the final nitrogen content of a steel will be determined by the ratio of the two effects to each other.

Open-hearth steelmaking

With steels from the open-hearth furnace, nitrogen is brought in by the metallic charge. Here, the scrap should be mentioned primarily, the nitrogen

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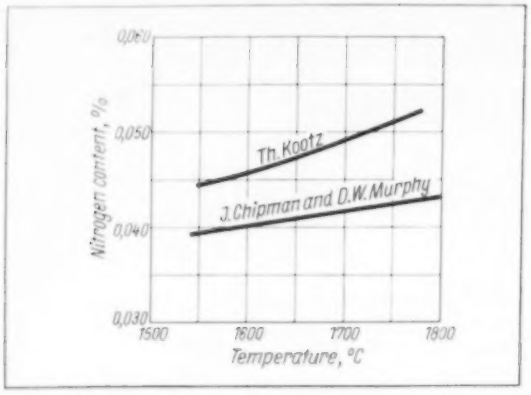

Fig. 1—Solubility of nitrogen in molten iron as a function of temperature.

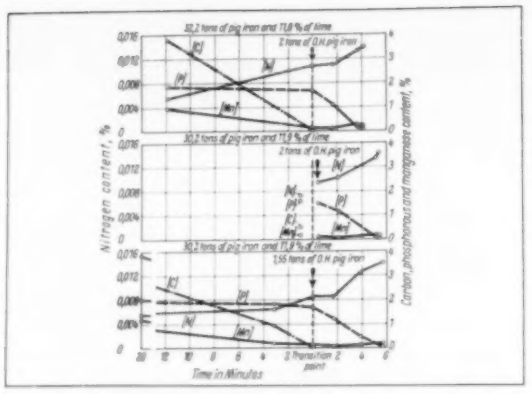

Fig. 2—Basic bessemer blows with an addition of open-hearth pig iron at the transition point.

content of which may vary within wide limits depending on its origin. Further nitrogen carriers are the pig iron added, the nitrogen content, which is normally from 0.004 to 0.008 pct N, and—in some cases—blown metal produced in another steel-melting unit, if the duplex process is used. The latter metal may have high nitrogen contents, particularly if blown metal from the standard basic or acid converter is used for duplexing.

During the melting period, no increase in nitrogen content of the charge in the open-hearth furnace by the fuel gases normally is to be expected. The same applies to the boiling period, since the slag cover protects the underlying bath from the absorption of nitrogen. On the other hand, there will be a steady decrease in bath nitrogen content during the boiling reactions and, to a lesser extent, during the melting-down period caused by the scavenging effect of the ascending carbon monoxide bubbles. The decrease in nitrogen content will be greater, the more vigorous the boiling of the bath and the higher the nitrogen introduced with the charge. The nitrogen content of molten open-hearth steel before tapping is normally within the limits of 0.004 to 0.007 pct, even if duplexing is used with larger amounts of blown metal from the converter. As could be proved by experiment, a fast removal of the higher nitrogen contents introduced takes place, in any case, because of the boiling reaction.

During tapping, the nitrogen content of rimmed and semi-killed steels remains constant. When tapping fully killed heats, a slight increase of nitrogen (0.001 pct) may be observed in many cases.

Electric-furnace steelmaking

The same considerations as have been summarized for the open-hearth apply, in principle, to the melting of steels in the electric furnace. But when producing high-quality steels, the refining is followed by a finishing period under a *white* slag. During this period no boiling reaction takes place, and the melt remains completely quiet in the furnace. In the finishing period there is again the risk of absorption of nitrogen, since all the nitrogen-removing effects are suppressed. Owing to the very high temperature of the electric arc, it is possible that the molecular nitrogen may be dissociated partly. Indeed, these are the reasons—compared with corresponding steels from the open-hearth furnace—why refined electric-furnace steels show somewhat higher nitrogen contents, which in the most unfavorable case may rise up to 0.012 pct N. This applies to unalloyed steels. If, in addition, alloying elements having a higher affinity for nitrogen are present, these values can be considerably higher.

Pneumatic processes

Pneumatic and special processes differ from the open-hearth process, to cite one way, in that the refining does not take place by the action of the oxygen present in the slag as an oxide, but rather by oxygen in the gaseous form reacting directly with the metal. The refining speeds are many times higher than those which can be obtained in the open-hearth furnace even under the most favorable conditions.

Nitrogen removal and decarburization

Before passing on to the description of the individual processes and their peculiar features, we want to discuss some fundamental results of an investigation on nitrogen removal during carbon combustion which apply to all these processes. In our own tests carried out in the basic 30-ton thomas converter,[1] we have artificially extended the effects of the foreblow period, which tend to inhibit the nitrogen absorption beyond the transition point by adding up to 2 tons of cold open-hearth pig iron at the beginning of the dephosphorization period, Fig. 2. Owing to the decrease of temperature and to a revival of the carbon combustion, the nitrogen content remains practically constant during the first two further minutes of blow, although the phosphorus content may already be lowered considerably. Nitrogen absorption does not take place before the open-hearth pig iron is dissolved.

Furthermore, the question had to be answered as to whether carbon combustion alone, without a simultaneous lowering of the temperature, could inhibit nitrogen absorption or even cause removal of nitrogen. For this purpose, several heats of liquid, basic-bessemer steel with nitrogen contents of between 0.018 and 0.026 pct were recarburized in the ladle and refined in a 3-ton baby converter by blowing pure oxygen on the top of the bath. The heats were followed up by taking several intermediate samples. The results, represented in Fig. 3, are convincing. In all cases the removal of the carbon

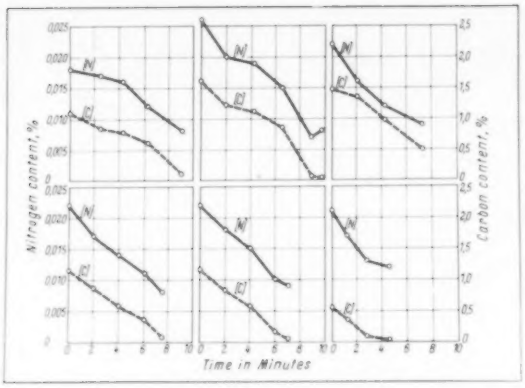

Fig. 3—Blowing of carburized basic-bessemer steel with pure oxygen in a 3-ton converter.

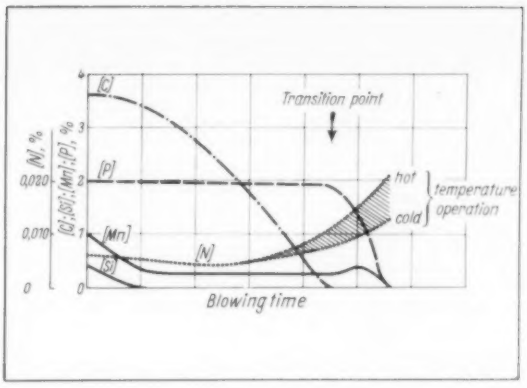

Fig. 4—Progress of refining when blowing basic-bessemer pig iron.

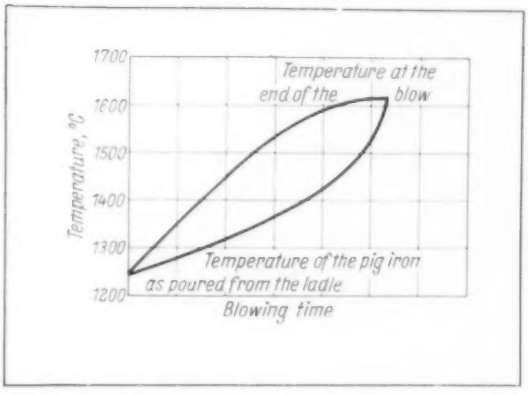

Fig. 5—Change of temperature during blowing in the basic-bessemer converter.

was accompanied by a decrease of the nitrogen content, in spite of the temperature increasing simultaneously. The striking feature in these diagrams is a certain parallelism of the curves which indicates that nitrogen absorption is connected with carbon combustion. This parallelism goes so far that, with a slow decarburization speed, nitrogen also decreases more slowly. A similar relationship between the nitrogen removal rate and the decarburization rate was found by C. Schwarz[5] for heats in the open-hearth furnace.

Acid-bessemer heats are completed with the removal of the carbon, but the decarburization period of basic-bessemer heats is followed by a further blow in order to remove the phosphorus. Opposing the nitrogen-removing tendencies caused by the scavenging effect of the carbon monoxide bubbles formed and the lowering of the partial pressure of nitrogen in the waste gases, there exists in both cases during decarburization, certain nitrogen-absorbing tendencies which normally predominate. These are the nitrogen being offered by the air blown, the length of the blowing period which determines the time of contact of the nitrogen blown-in with the melt, and the temperature rise during the course of the blowing operation. The result, in practical operation, is that the nitrogen content increases slowly during the decarburization period. With basic-bessemer heats, this is followed by an additional blowing period to remove the phosphorus; the washing-out effect of the carbon reaction is absent in this period. Since all the oxygen of the blast, and beyond that, oxygen from the slag already formed, will be used up during this time for the slag-forming reactions (Mn-hump), the converter gases practically consist of pure nitrogen. The result of both effects will be that the nitrogen content of basic-bessemer heats increases quickly during the dephosphorization period. The trend of the effects of these most critical variables is indicated in Fig. 4.

The effect of temperature

The effect of temperature should be mentioned among the variables influencing nitrogen absorption. For the final nitrogen content of bessemer steels, not only the magnitude of the finishing temperature, but also the changes in the temperature during blowing, is of importance. Starting from the temperature of the pig iron poured in, to the temperature of the heat after completion of the blow, any path whatever will be possible between those paths of temperature movement indicated schematically in Fig. 5. Of the two extreme cases shown in Fig. 5, the heat running at the top limit of the temperature shows the higher final nitrogen content, although the same final temperatures are present in both cases. This results in the higher speed of nitrogen pick-up. If steels low in nitrogen are to be produced a temperature movement of the heat corresponding approximately to the bottom curve in Fig. 5 should be maintained during blowing. This may be accomplished by adding cooling agents, such as ore, limestone, sinter, or scrap in small pieces. Generally, the nitrogen content of bessemer steels will be higher, the higher the temperature during blowing and at the completion of the blow.[6]

Besides the already-mentioned variables which control the nitrogen content of bessemer steels, we may mention the geometric nature of the converter, e.g., the bath level, cross section, age of the converter, and age of the bottom, etc.[7] Our French friends of the Institut de Recherches de la Siderurgie have done much research work in this field which cannot be discussed in detail within the scope of this paper. From the preceding considerations, how-

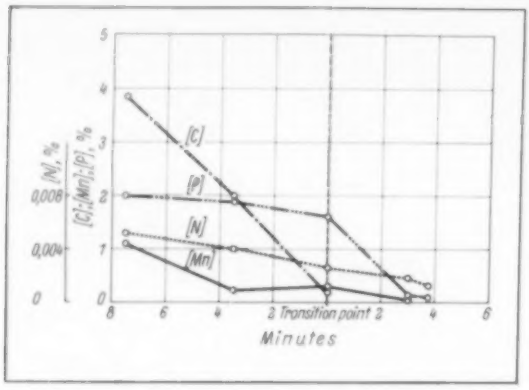

Fig. 6—Progress of refining when blowing with O_2-CO_2 mixtures in a 3-ton converter.

ever, it may easily be understood that the nitrogen content of bessemer steels is the result of the sum of the effects of a multitude of single factors, which are individually known and are taken into account in blowing, but which lead to the final result that with such steels, a certain dispersion of the nitrogen content will always have to be expected.

Oxygen-enrichment

The same considerations apply to converter steels which are refined with oxygen-enriched air. In principle, the metallurgical reactions are not changed. Owing to the decreased nitrogen content in the blast and to the shortened blowing times, however, lower final nitrogen content is obtained. Several years ago the bessemer steel plants of Western Europe changed over to blowing with oxygen-enriched air. The reasons for this change are to be found in the possibility of producing steels with lower nitrogen content and, to a greater extent, in decisive economic reasons. The shorter blowing times and the possibility of an increased use of scrap have led to an expansion of production, without the necessity of enlarging existing plants.

In the bottom-blown converter, an unlimited enrichment with oxygen is not feasible; the limit lies at about 38 pct O_2 in the blast. If higher contents are used, the tuyeres will be attacked too heavily, and a premature wear of the bottoms will be the result.

In conjunction with the refinement by oxygen-enriched air, the *oxide-film theory*, established for the first time by G. Naeser,[9] is of particular importance regarding the nitrogen absorption of the steel. The theory starts from the supposition that every gas bubble coming off from the tuyere bottom will be enveloped by an oxide film on account of the oxidation of the iron surrounding it. As long as this film is uninterrupted, the iron will be protected against any absorption of nitrogen. It is not until this film is used up—owing to progressive refining reactions—and ceases to be continuous, that the nitrogen can be absorbed by the iron. How long the film remains intact, is a question of reaction kinetics and the amount of oxygen offered.

In steels which are made according to the conventional air-refining processes, and for which air is exclusively used as the refining agent, the nitrogen contents—even if low temperatures and favorable converter conditions are maintained—are considerably higher than the nitrogen contents of comparable steels elaborated in the open-hearth and electric furnace. The use of oxygen-enriched air, together with adequate additional measures, however, enables the nitrogen content to be kept so low that it even approaches those of the open-hearth steels.[9]

Blowing with nitrogen-free gas

Very low nitrogen contents—below those of conventional open-hearth steels—may be obtained by the use of gases and vapors free from nitrogen.[10] Here the development has proceeded in different ways. Still blowing through the tuyere bottom, phosphorus containing pig iron (basic bessemer pig iron) is refined today in the basic-lined converter with mixtures of pure oxygen and steam or oxygen and carbon dioxide. The mixing ratios of oxygen to steam and carbon dioxide are normally between 1:1 and 1:1.2, respectively. The heat requirements when using these ratios are balanced to the extent that there may be no further additions of cooling scrap. Major changes of the indicated mixing ratios in the direction of an increase of the oxygen addition are impossible for reasons of the life of the bottoms and of the converter. The metallurgical aspect of the process, as compared with that of the normal basic-bessemer process, changes only in that from the beginning of the blow a continuous decrease of the nitrogen content of the heat to final contents of 0.001 to 0.003 pct N is observed. Fig. 6 illustrates such an example, the refining process of a baby converter heat which has been blown with a mixture of oxygen-carbon dioxide.[11] The method of blowing with oxygen-steam and oxygen-carbon dioxide mixtures has been introduced in Europe into the practical steel plant (see JOURNAL OF METALS, October 1958, p. 669).

With the exclusive use of technically pure oxygen as the refining agent, oxygen may no longer be blown through the tuyere bottom, since the bottom would be destroyed in a very short time. The oxygen, therefore, is blown onto the surface of the bath by means of a water-cooled nozzle. The first trials in this direction were initiated before World War II at the Technische Hochschule, Berlin-Charlottenburg, under the direction of R. Durrer. He continued with these trials until 1948 in the plants of the Rollsche Eisenwerke at Gerlafingen (Switzerland).[12] It is especially due to the Austrian metallurgists at Linz and Donawitz that this process has been suitably developed for large-scale operation for pig irons containing small amounts of phosphorus (open-hearth pig iron). Using this so-called LD process, considerable amounts of steel are produced all over the world today.[13]

In principle it is also possible to refine pig irons rich in phosphorus by blowing pure oxygen onto the bath.[14] With up to 0.5 pct P in the pig iron, the blowing technique as used with the LD process can be maintained in its essential features. If one operates in the same manner with still higher amounts of phosphorus, then remarkable portions of phosphorus will be left in the heat after the completion of the carbon combustion. Practically, the process proceeds in a similar way to the bottom-blown converter, but it is made difficult in so far that after completion of the decarburization, the reactions between metal and slag proceed more slowly and an unnecessarily high amount of iron is scorified, since the bath movement is missing. The process, therefore, must be directed in such a way that, with a

formation of an early slag, the phosphorus is oxidized simultaneously with the carbon. The dephosphorization may be driven so far that the phosphoruc content will be practically removed at the time when high carbon contents are still present in the heat. This method of operation has the advantage that the carbon combustion and the bath movement connected therewith will be maintained until tapping. The reactions proceed in a similar way as in the open-hearth furnace, though perhaps in a correspondingly shorter time.

In order to promote an early formation of slag, a process has been developed in Sweden which has become known as the *Kaldo process* (**Kal**ling-**Do**mnarvet).[15] A basic-lined drum inclined at an angle of about 17° to the horizontal rotates at about 30 rpm around its longitudinal axis. As refining agent, pure oxygen is blown onto the surface of the bath by means of a water-cooled nozzle.

The Oberhausen rotor process operates on the same principle.[16] The differences as compared with the Kaldo process are that the rotating drum is longer, the rotation speed considerably slower (½ rpm), and the oxygen is blown partly into the heat and partly onto the surface of the bath. The two processes are at present in the state of their large-scale evaluation, and future development will decide which one finally succeeds.

In all processes which are making use of gases and vapors free from nitrogen, the nitrogen introduced by the pig iron is decreased during decarburization by the scavenging effect of the carbon dioxide formed. There are no effects leading to nitrogen absorption. In this manner, steels can be produced, the final nitrogen contents of which are most frequently between 0.002 and 0.004 pct N.

Comparison of processes

In Table I, the nitrogen contents to be expected with the various steelmaking processes are summarized. The table also indicates the limits of analysis of the remaining elements. The scatter range of the final temperature will be higher for all pneumatic processes—including those processes using pure oxygen as a refining agent—in comparison with the scatter range of the final temperature for the open-hearth and the electric-arc process. Obviously it will always be difficult to give precise data on the limitations of a process. The summary in Table I has to be considered in this sense, but it is justified as a first approach and may be of benefit under due consideration of what has been said before. The values as indicated in Table I involve last samples from the furnace and converter, respectively.

Aging and embrittlement

When dealing with the technological properties of the steels made by the various processes—in particular, the different nitrogen contents—the question immediately arises as to their susceptibility to aging and their tendency to embrittlement. Up to now, the causes of susceptibility to aging are not fully understood. Very early, suspicion was cast on the deleterious effects of higher phosphorus and nitrogen contents. Reference may be made in this respect to the formula pct $P + 5 \times$ pct $N_2 \leq 0.090$ which was established in 1910 by Stromeyer for the assessment of the quality of a steel.[17] This formula is still accepted by many research workers. Within the scope of this paper it is not intended to discuss in detail the phenomenon of aging and its possible variables.

Distinction should be made between aging in the precise sense and the embrittlement phenomena occurring during cold deformation. Whereas the latter remains unaffected by the nitrogen content, it is safe to assign an effect of nitrogen in the deterioration of the toughness which is connected with the process of aging. Furthermore, it is important that the susceptibility to welding cracks be considered as being dependent upon the nitrogen content in so far as rimming-type steels are involved. These are some of the reasons why so much stress is laid upon maintaining low nitrogen contents in the improvement of existing processes and in the development of new blowing processes.

The possibilities of accomplishing this have been realized by the large-scale production of oxygen and by its use in the production of iron and steel. The development started after World War II. Today, the European basic-bessemer steel plants are making wide use of the oxygen-enriched blast as a refining agent for the production of their steels and, apart from an increase in production, they have also succeeded in drawing qualitative benefits of these processes. Considerable proportions of the total production of basic-bessemer steel are blown as so-called *improved converter steels* (Vk steels) which, in their specifications regarding the level of the P and N contents, are confined to certain maximum values, and which in their chemical analysis correspond to rimmed open-hearth steels of similar types.

Table I. Composition Limits in the Various Steelmaking Methods

Method	Last Converter and Furnace Test, Respectively					
	C, Pct	Mn, Pct	P, Pct	S, Pct	O, Pct	N, Pct
Acid converter, air	>0.03	0.20-0.50	0.040-0.100	0.030-0.050	0.030-0.080	0.010-0.020
Basic converter						
air blown	<0.02	0.15-0.25	0.040-0.100	0.025-0.035	0.060-0.100	0.010-0.025
O_2-enrichment	<0.02	0.10-0.20	0.030-0.070	0.020-0.030	0.060-0.100	0.006-0.012
O_2-H_2O	<0.02	0.05-0.15	0.020-0.040	0.015-0.025	0.060-0.100	<0.004
O_2-CO_2	<0.02	0.05-0.15	0.020-0.040	0.015-0.025	0.060-0.100	<0.004
LD process						
O_2, OH pig iron	>0.03	0.40-0.60	0.015-0.040	0.010-0.020	0.010-0.050*	<0.005
O_2, basic-bessemer pig iron	>0.03	0.10-0.20	0.020-0.040	0.015-0.025	0.010-0.050*	<0.005
Kalling-process, basic-bessemer pig iron	>0.03	0.10-0.20	0.015-0.040	0.015-0.025	0.010-0.050*	<0.005
Basic open-hearth furnace, without O_2	>0.05	0.15-0.50	0.020-0.040	0.025-0.040	0.010-0.050*	0.004-0.007
Basic open-hearth furnace, using O_2	>0.02	0.05-0.40	0.015-0.040	0.015-0.030	0.010-0.050*	0.004-0.007
Basic electric-arc-furn., without O_2	>0.05	0.10-0.40	0.010-0.030	0.005-0.015**	0.010-0.050*	0.004-0.010
Basic electric-arc-furn., using O_2	>0.02	0.05-0.30	0.010-0.030	0.005-0.015**	0.010-0.050*	0.004-0.010

* Depends upon the respective carbon content.
** Under *white* slag.

Aluminum-killed steels

In conclusion, we should touch on another development which was initiated a few years ago, the outcome of which cannot yet be foreseen. It is possible to make use of the nitrogen content as a desired alloying element to improve the properties of killed steels, if use is made of the strong affinity of aluminum to nitrogen. When killing steels with aluminum, the nitrogen will be fixed as aluminum nitride (AlN) which, by an adequate treatment of the steel, is precipitated in a finely divided form, promoting at the same time the formation of a fine grain. This leads to remarkable improvements in the technological properties.[18] It is worthy of notice that the fine grain caused by nitride precipitation is so significant in its effect on the resistance to rupture, that the effect of higher phosphorus contents will be completely masked. Up to 0.1 pct P in the steel, for instance, the notched bar impact strength and the location of the notch toughness-temperature curves remain unchanged.[18, 19]

This accomplishment of course, opens a wide field of application to bessemer steels and particularly to basic-bessemer steels. By making use of the fixation of nitrogen by aluminum and the technological improvements brought about by it, the properties of a steel can be changed at will within wide limits and can be adapted to specific applications.

The chemical composition and the mechanical properties of a series of basic-bessemer steels which have been killed by silicon and aluminum are shown in a paper of H.-J. Wiester, W. Bading, H. Riedel, and W. Scholz.[18] They show that by utilizing the effect of nitride precipitation, and with a corresponding variation of the other accompanying elements, it is possible to produce steels in the converter which cover a wide range of tensile strengths and which exhibit good toughness properties and—with a corresponding confinement of the carbon content—an excellent weldability as well.

The utilization of nitride precipitation must not necessarily be confined to bessemer steels, where the nitrogen content is already more or less high by the very nature of the process. It is also entirely feasible to make use of the effect of this ultimate nitrogen absorption in open-hearth steels or in steels having been produced according to one of the special processes mentioned above.

Summary

Nitrogen dissolved in steel originates, on the one hand, from the material charged, and the level of the final nitrogen content is, on the other hand, dependent on the process applied. According to the basic investigations carried out by A. Sieverts, nitrogen is dissolved in steel in its atomic state. Its solubility is governed by the so-called *square root law*. The maximum solubility of nitrogen, which is already known by the investigations of J. Chipman and D. W. Murphy as well as of Th. Kootz, will not be reached in the large-scale production of steels, since the nitrogen absorption is very slow even in the presence of high amounts of nitrogen (molecular nitrogen). With the atomic nitrogen, however, a considerably more rapid nitrogen absorption is possible.

In steels produced by the open-hearth process, the nitrogen is introduced with the charge. During melting-down and particularly during the boiling period, the nitrogen decreases continuously. In open-hearth steel melts, there will be no nitrogen absorption through the gas phase. With electric-arc furnace melts, there is the risk of a nitrogen absorption, particularly during the finishing period, by the *focal point* effect of the arc between the electrodes and the melt.

With bessemer steels, nitrogen absorption takes place from the gas mixture blown through the bath. The nitrogen content is dependent, in the amount of nitrogen blown through, on the time of contact of the nitrogen with the bath, and on the temperature. The paper deals, furthermore, with the effect of an oxygen enrichment of the blast. The nitrogen contents obtainable in the bottom-blowing converter are summarized, and the most favorable methods of operation are described.

Very low nitrogen content may be obtained in the converter with the use of gases and vapors free from nitrogen. The reactions proceeding when blowing with oxygen-steam and oxygen-carbon dioxide mixtures are discussed. The final nitrogen contents obtainable as well as the particular features of the process are described.

When using pure oxygen as a refining agent, the use of tuyere bottoms is no longer possible, since the bottom would be destroyed in a very short time. In this case, the oxygen is blown onto the surface of the bath by means of a water-cooled nozzle. The refining reactions occurring in blowing pig iron with low and high contents of phosphorus by using pure oxygen, as well as the new processes (LD process, Kalling-drum, Oberhausen-rotor) are described together with their metallurgical features.

This is followed by a summary of all processes and of the nitrogen contents obtainable in the steels made according to these processes. The effect of the nitrogen content on the properties of killed and rimmed steels is discussed briefly.

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PLUTONIUM METALLURGY IN THE UNITED KINGDOM

Completely "left out" of US wartime developments in plutonium, Britain has advanced rapidly in the intervening years, due largely to the economic advantages which this material holds in reactor development. A JOURNAL OF METALS *exclusive, this article is written by a leading British plutonium metallurgist.*

by M. B. Waldron

DUE to the lack of large domestic uranium sources and the high cost of electric power in the UK, it was recognised from the earliest days that plutonium would occupy a prominent place in the nuclear developments of that country.

It was known that the enrichment requirements necessary for the establishment of a progressive reactor development program could be satisfied in two ways: by building diffusion plants for separation of enriched uranium, or by adopting plutonium enrichment, which would require conventional chemical separation plants with certain special precautions connected with the high degree of toxicity associated with plutonium.

In the US, advantage has been taken of relatively cheap electric power and the incentive of wartime developments to set up diffusion plants and rely largely on enrichment of U^{235}. While this involves a high capital investment, it has the immediate advantage of enabling large quantities of enriched material to be obtained from available uranium deposits.

In Britain, however, where cheap electric power is unavailable, plutonium enrichment has greater attraction. It is part of the UKAEA's policy to pursue plutonium enrichment and recycling with the objective of introducing plutonium enrichment in power reactors on the scale of at least 3 tons per year, in the years 1970 to 1975.[1]

To meet this timetable, it is necessary that a comprehensive evaluation of plutonium fuels be well advanced by the middle sixties. As a result, plutonium metallurgy is currently entering a critical state of development and selective exploitation in the British program. The restricted technical manpower reserves in Great Britain has served to heighten the challenge encumbent on the plutonium metallurgists to make the most effective use of their endeavors.

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Early plans

Plans were made for plutonium metallurgical laboratories at both the Atomic Energy Research Establishment (AERE) at Harwell and the Atomic Weapons Research Establishment (AWRE) at Aldermaston in 1947, although it was not until the end of 1948 that the first plutonium available to British workers was extracted from uranium irradiated in the NRX Reactor at Chalk River, Ontario. This formed the basis of micrometallurgical investigations by Harwell's J. Milsted at Chalk River.[2]

Although plutonium metallurgy had reached an advanced stage in the American laboratories by this time (the first metal having been produced by the metallurgical project at the University of Chicago in 1943), for reasons of military security little knowledge of either the achievements or the methods used were available to British scientists and engineers. Indeed, little was known of the precautions necessary to maintain safe conditions in the laboratory, apart from the permissible activity levels recommended by the International Commission on Radiological Protection.[3]

When it is recalled that these recommendations are so stringent that the permissible total body burden is set at 0.6 μg, which corresponds to a plutonium particle only 30 μ in diam, it will be appreciated that a formidable problem confronted the early experimenters in deciding how to set up metallurgical experiments. It was not until 1954 that the benefit of the valuable work done at Los Alamos and elsewhere became available in any degree to research workers outside the American continent.[4, 5]

Nevertheless, the laboratories planned on the drawing board in 1947 were completed and available for active experimentation long before the first few grams of plutonium became available in 1951. Since then, many changes have been introduced into the plutonium laboratories as fresh experience has become available.

A limitation common to all stages of plutonium operations is that imposed by the critical size for

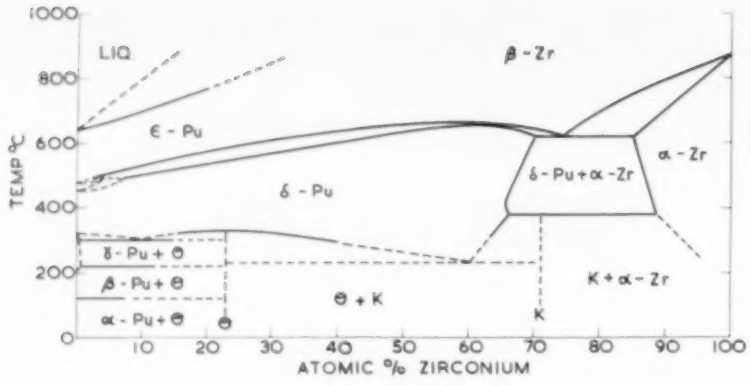

Fig. 1—Phase diagram of the plutonium-zirconium system.

neutron multiplication. For plutonium metal this is of the order of a very few pounds, dependent upon dilution and environment, and is, in general, smaller in solutions owing to the moderating action of water. Thus, batch sizes must be restricted and carefully controlled at all stages to prevent the accumulation at any one point of an excessive amount of fissile material.

Two developments might be mentioned at this stage because of the impetus they gave to plutonium metallurgy. The AWRE team of metallurgists were required to provide the necessary information for the production of plutonium components for the first British atomic weapons trial at Monte Bello, scheduled for October 1952.[6] Since their laboratories were not available until the middle of 1951, some of the preliminary work was done in facilities available at AERE. This collaboration led to a useful pooling of early experience and ideas.[7] At AERE the first major commitment was the production of a complete plutonium charge for the zero-energy fast reactor experiment, ZEPHYR, in 1953. These projects necessitated the rapid acquisition not only of basic knowledge concerning the properties of plutonium metal, but also of the techniques for handling the material on the kilogram scale, including an assessment of casting, pressing, forging, machining and canning of metal fuel rods, and the successful continuous operation of extended glovebox lines.

The program at AWRE has included a considerable proportion of basic research not limited to weapon applications. At the present time, physical properties of plutonium metal at both elevated and low temperatures have been studied and the work reported in a number of papers.[8, 9] In addition AWRE has undertaken a large-scale fabrication of plutonium fuel elements for a zero-energy reactor and is well equipped for research and development projects of this kind.[10]

At AERE it is intended that plutonium research should be as fundamental as possible. This includes the development of fuel technology for advanced types of reactor systems, but is not intended to involve the solution of problems related to a specific reactor application. At present, the entire plutonium metallurgical effort is confined to AWRE and AERE, but laboratories are now being commissioned at Dounreay Experimental Reactor Establishment (DERE) which will be capable of taking over the development of fuels for proposed civil reactors, including the Fast Reactor which has been built there.

Preparation

The extractive metallurgy of plutonium is limited to the separation of plutonium from uranium in which it is formed by neutron irradiation. These processes in many ways involve fairly conventional chemical engineering practices, and have been described in detail in a previous publication.[11] The objective is to produce plutonium free from certain impurities to extents which depend upon their ability to absorb neutrons. Thus, it may be important to extract an impurity such as boron to an extremely low level, while from a nuclear point of view, relatively large proportions of an element such as aluminium would be permissible. Some attention must be paid to the influence of the impurities on metallurgical stability, oxidation resistance, and fabrication behavior of the metal to be sure that the permitted specification is technically satisfactory, from a nuclear standpoint.

Physical properties

In the earliest work by Milsted at Chalk River,[2] the measurements of density showed evidence of the allotropy of plutonium, the ingots having specific gravities in the region of either 16 or 18, with associated differences in their X-ray patterns and ductility. Even when the first reductions were made on the kilogram scale, billets having different histories and consequent impurity contents, showed marked variations in metallurgical behavior. These early experiments were rather confusing, but it was clearly recognised that there were at least five allotropic modifications whose characteristics were evidently strongly affected by impurity contents. It has been mentioned elsewhere that these early results gave clear evidence of the presence of a sixth modification,[12] and definite attempts were made to establish the existence of this phase, now known as δ', since consistent indications were obtained with dilatometric and thermal analysis measurements. Early investigators were baffled by the inability of the high-temperature X-ray powder technique to detect phases other than δ, $\delta + \epsilon$, and ϵ, over the relevant temperature interval. The subsequent work of Ellinger and Elliott has shown that a number of impurities, silicon in particular, readily suppress the existence of δ'. The reaction between plutonium powder specimens and the silica quill at the temperatures involved would quickly lead to contamination by silicon, only a few hundred parts per million being sufficient to suppress the appearance of δ'.

Fig. 2—Top: Uranium—10 pct Pu alloy irradiated at 400°C to 0.29 pct burnup. Bottom: Zirconium—40 at. pct Pu alloy irradiated at 500°C to 0.83 pct burnup.

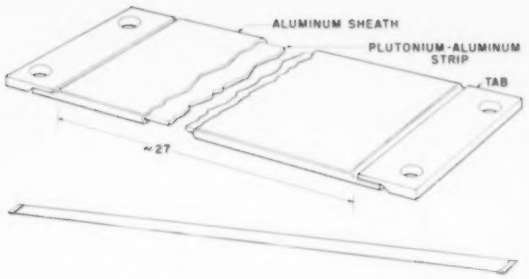

Fig. 3—Cut-away sketch of the completed AWRE aluminum-sheathed plutonium fuel element, which is 1.2 in. wide and 0.020 in. thick.

Table I—Comparison of Thermal and Electric Properties of Several Trans-Uranium Elements

	Resistivity, Ohm Cm x 10^6	$\sigma/M\rho^{2/3}$ x 10^2	Atomic Heat, Cal Per G Atom
Th	13	1.17	8.0
U	25	0.68	6.6
Np	120	0.27	7.1
Pu	150	0.17	8.0

The details of physical property measurements undertaken in British laboratories, including crystal structures, expansion behavior, electrical properties, thermal emf, thermal conductivity, specific heat, magnetic susceptibility, and certain mechanical properties, have been published.[6, 8, 9, 12 to 16]

This information is not only of direct technological value, but is part of a broader investigation of the physical properties of the heavy elements in which comparable measurements have been, or are, currently being made in thorium, uranium, neptunium, and plutonium.

While it will still be a long time before any consistent picture of the behavior of these elements is evolved, a number of interesting comparisons are already coming to light. For example, electrical resistivities and specific heat values of these materials, given in Table I, show that there is a progressive upward trend, which in the case of the resistivity is an extension of the observed behavior in earlier groups of elements, the transition metals and the rare earths, while the specific heats are all considerably in excess of the Dulong and Petit values, suggesting high electronic contributions. It is to be expected that much of the differing behaviors of these elements may be related to the arrangements of their electrons, since the relative energies of the different species of electrons, 5f, 6d, and 7s, become interchanged on moving along the series. In order to understand these effects more fully, measurements are being extended down to liquid helium temperatures where the electronic contributions are distinguished more clearly from those of the crystal lattice.

Alloying behavior

The plutonium produced by normal irradiation of uranium is almost pure nuclear fuel, in contrast to natural uranium, of which only 0.7 pct is directly useful for fission. Consequently, it is necessary to dilute the plutonium so that the heat generation is easily controlled. This is convenient because a material whose melting point is as low as 640°C and which exists in six distinct allotropic modifications below this temperature, with substantial changes of density between the various phases, is not an attractive engineering material. The search for suitable dilutents involves the study of both alloys and ceramic compounds.

In the case of alloys, experience with uranium fuels would suggest three possible lines of development, all of which have been pursued in the alloy programs that have occupied British laboratories. First is the formation of solid solutions based on the two cubic forms of plutonium, δ and ϵ; second is the formation of dilute solid solutions of plutonium in suitable matrix elements; third is the dispersion of a hard plutonium-bearing compound in a suitable matrix. In exploring the occurrence of these types of alloys, it is natural to seek means of eliminating as many systems from consideration as possible; the accepted rules of alloy behavior, such as those proposed by Hume-Rothery, Raynor, and others may be used to this end. In attempting this, allowance must be made for the effective atomic size of plutonium in its various modifications, which is sufficiently larger than that of uranium to mean that close analogies with the latter will not be possible, especially in view of other dissimilarities, such as melting point and allotropy. Account must also be taken of the ignorance of its effective valency and whether rare earth or transitional metal behavior is to be expected.

The initial systems to be established were those which fell into the first class, since experience with other elements showed that a study of such solid solutions greatly advanced our fundamental knowledge of the metals concerned and at the same time provided metallurgically interesting materials. Among these systems were the alloys of plutonium with aluminum,[16] thorium,[17] uranium,[18] and zirconium,[19] all of which have been studied at Harwell and reported on elsewhere. The BCC ϵ-phase of plutonium unfortunately does not form nearly such

extensive solid solutions at its counterpart γ-uranium. This is because of the existence and greater stability of δ-plutonium and the formation of stable intermetallic compounds. No system has yet been found in which a solid solution based on ε-plutonium is stable from a high temperature, e.g., 1000°C, down to room temperature. Fig. 1 shows the equilibrium diagram for the Pu-Zr system[18] in which the extensive δ-phase and ε-phase solutions are noteworthy, but in which a $\delta \rightarrow \epsilon$ phase change occurs about 600°C over the interesting composition range for a fast reactor fuel—around 40 at. pct Pu. The existence of such a phase change would be expected to affect adversely the irradiation stability of any fuel whose temperature exceeded such a transformation.

The δ phase solid solutions are being studied actively as an extension of the physical property measurements on the unalloyed metal. The negative coefficient of expansion of the FCC δ-plutonium and the abnormal FCC δ-phase ⇌ BCC ε-phase contraction suggested that the study of these phases would be particularly informative. It has already been shown that an addition of aluminum reverses the abnormal signs of the coefficients of expansion and resistivity.[18]

The search for plutonium alloys of the second type also involved an identical selection of systems for examination, of which uranium-plutonium, thorium-plutonium, and zirconium-plutonium have proved to hold special interest. For example, in Fig. 2 it will be seen that a substantial amount of plutonium dissolves in both the α and β forms of zirconium so that single phase zirconium alloys can be obtained with up to 10 pct plutonium over a wide temperature range; even if the $\alpha \rightarrow \beta$ transition at 750-850°C is exceeded, the passage through this transformation would not be expected to be metallurgically disastrous. Thorium base alloys are of interest because thorium dissolves up to 50 pct Pu in its α-form; not only is this technologically useful, but it underlines the considerable differences that can arise in the behavior of uranium and plutonium. In the uranium-thorium system there is virtually zero mutual solid solubility and immiscibility in the liquid state.

The third category of alloys is represented by plutonium-aluminium and plutonium-iron, where the hard compounds $PuAl_4$ and $PuFe_2$ are dispersed in matrices of aluminum or iron, in which there is no appreciable solubility for plutonium. The latter system has been actively studied in Britain and the diagram independently established.[18]

Irradiation studies

Possibly the most vital information in the evaluation of a nuclear fuel is a measure of its stability under irradiation. This may be investigated in a number of ways, including the limiting case of the full term irradiation of experimental fuel elements in a test reactor. Short of this full scale test, it is not possible to simulate fuel element behavior in an accelerated test without introducing divergencies which may jeopardise the interpretation of results. For this reason, British practice has been to test specimens small enough to enable their temperature to be moderately uniform and accurately measured, and to keep variations in irradiation damage from center to outside due to opacity to neutrons within a reasonable level.

A number of different types of plutonium-bearing fuels have been irradiated and examined.[19] This has involved the provision of α-active post-irradiation cells for a wide range of physical measurements (particularly metallography, density measurement, powder metallurgy, and fission product gas release) in addition to those established for uranium-based fuels. While not all the fuels examined have been promising, there are some that have shown excellent stability, and in other cases an analysis of the first round of irradiation tests has suggested ways of obtaining more satisfactory behavior. Fig. 2 gives two typical irradiation samples, one showing the rather serious damage obtained with a burn-up of 0.29 pct at a temperature of 400°C of a binary U-10 wt pct Pu alloy, while the other shows the excellent behavior of a plutonium-zirconium alloy irradiated in the extreme zirconium rich end of the δ-phase field shown in Fig. 1 to 0.83 pct burn-up at 500°C.

In assessing the results from these tests, however, it is important to bear in mind that irradiation behavior is very sensitive to surface temperature of the specimen. Experiments with larger samples that have been reported in the US often had much cooler surfaces than the nominal center temperatures quoted.

Fabrication studies

The first plutonium fabrication program for reactor purposes[6] was the production of over 300 elements, each containing two cast plutonium-rich alloy rods for the zero-energy reactor experiment, ZEPHYR, as mentioned earlier. These rods were approximately ¼ in. diam, 3 in. long, precision cast, copper-capped, and sealed in welded nickel cans. After an initial development period for setting up the necessary gloveboxes, which were of a new free-standing type to enable all-round access to the equipment, the bulk of the charge was produced in approximately 6 weeks.

A smaller fabrication experiment was conducted in 1956, when some 20 rods, approximately 1 x 8 in. were produced in a dispersion of PuO_2 in thorium.[19] This production demonstrated that plutonium-bearing fuels could be produced with little additional complexity due to α-activity. Thorium powder, −300 mesh, and −100 mesh PuO_2 powder were weighed out in a glovebox and loaded into screwtop jars which were sealed in polyvinyl chloride(PVC) bags and rotated on an inactive mill to achieve thorough mixing. The mixed powder was then carefully loaded into another PVC bag assembly, after which a cold-compacted bar was produced by hydrostatic pressing. The compact was sintered in an active furnace and finally machined on a lathe installed in a glovebox. It was found that the dimensional consistency of the sintered product was such that less than 0.030 in. needed to be removed by machining, a figure that would undoubtedly be improved by full production under suitably controlled conditions.

A third fabrication experiment was the production at AWRE of Al-Pu alloy elements, 1.2 in. wide, 27 in. long, and 0.020 in. thick which involved setting up a complete suite of boxes for casting, hot- and cold-rolling, canning, and inspection.[20] Construction detail is shown in Fig. 3.

Apart from specific operations of this type, a continuing program of fabrication research exists at each of the plutonium laboratories. These are based on both resistance and high-frequency melting,

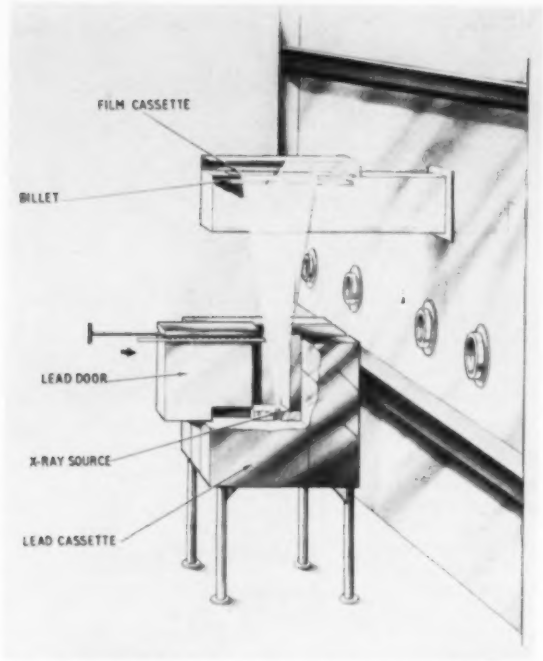

Fig. 4—Sketch showing the method used to radiograph plutonium-aluminum alloy billets at AWRE.

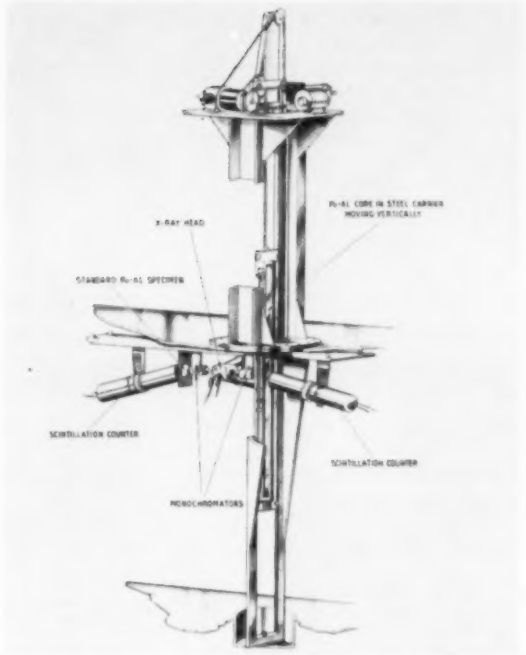

Fig. 5—Sketch showing the X-ray equipment used to determine the uniformity of plutonium content in plutonium-aluminum alloy strip at AWRE.

tungsten- and consumable arc melting, cold- and hot-rolling mills, extrusion presses, powder metallurgy, and other metallurgical techniques. At AERE, the objective is to establish in outline the fabrication techniques that may be necessary for the various classes of potential fuel under active investigation, while at DERE any one fuel may be studied to determine the detailed production process for a particular reactor application.

Ceramics and cermets

In order to make the most effective use of the staff and facilities available, plutonium ceramic research initially was kept to a small scale until the significant differences between the plutonium and uranium compounds had been established. This preliminary work [19, 20] has demonstrated that the oxides of the two show notable differences in stability which may have important repercussions in their application. Whereas UO_2 exhibits non-stoichiometry in the direction of higher oxygen contents, PuO_2 scarcely exceeds the nominal composition, thus excluding many of the aspects of behavior that can be attributed to non-stoichiometry of UO_2. On the other hand, PuO_2 can be reduced to the lower oxide, Pu_2O_3, which may have an adverse influence on the stability of solutions based on PuO_2, particularly when dispersed in a cermet. A system of considerable interest is the enrichment of UO_2 by relatively small amounts of PuO_2, and the preparation, irradiation behavior, and properties of these mixtures is being studied. At the same time, the characteristics of other compounds and of solutions of plutonium in other ceramic matrices, such as alumina or magnesia, are being examined.

In conclusion, it may be said that in Britain, the year 1959 sees the emergence of plutonium metallurgy from a period of intensive exploration to a new phase of exploitation, in which research on the scale of grams has to be applied to the problem of using plutonium by the ton. No more than eight years have elapsed since the first meaningful experiments were carried out in British laboratories, a length of time which must be considered short for the establishment of any industry of the complexity attached to nuclear metallurgy, particularly when the additional restrictions of radio-active toxicity must be overcome. The territory to be covered in the next eight years permits no respite for those who have elected to work in this interesting but arduous field.

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AIME NEWS

Northern Ohio's NOHC Meeting Features UCM's McKeon on Alloys

William T. McKeon, Union Carbide Metals Co., was the featured after-dinner speaker at the Annual Meeting of the Northern Ohio section, National Open Hearth Steel Committee. The meeting, for which 327 registered, was held at the Pick-Ohio Hotel, Youngstown, on March 12th.

Mr. McKeon spoke on *Alloys for the Present and Future*. He summarized advances of recent years, such as exothermic manganese giving savings up to $1.00 per ton in overall costs; electrolytic manganese with low carbon content for deep-drawing steels; and packaged ferro-alloys to eliminate weighing on the charging floor and to reduce material handling costs. Vacuum-melting techniques are expected to produce many of the alloys needed in the future.

Robert P. Hill, superintendent, electric furnaces, Roemer works, Sharon Steel Corp., served as toastmaster. The Rev. Henry J. Cibulka, Pastor of St. James Church in Youngstown, gave the invocation.

Lead-off speaker at the technical session was Robert Edwards, asst.-superintendent, steel works, Jones & Laughlin Steel Corp., Aliquippa, Pa. In speaking on the *Basic Oxygen Process*, Mr. Edwards summarized the first 15 months of operating data at Aliquippa LD steel plant.

Ingotrol-Weighing Ingots as Teemed was the subject of a paper by R. G. Watson, product engineer, Republic Steel Corp. He described the development of a weighing spreader beam for the ladle, an automatic stopper control device, and control circuits for automatic stopper cut off. Ingots can thus be poured to the proper weight and crop loss is thereby reduced.

R. C. Oswald, superintendent, open hearths, Roemer works, Sharon Steel Corp., presented a paper on *Refractory Gunning for Open Hearth Furnace Maintenance*. At Sharon Steel Corp. backwalls and roofs were sprayed with chrome. Down time during campaigns has been virtually eliminated. Roof life has been increased to an average 172 heats without patches.

High Carbon Rimming Steels were described by John Beale, asst.-chief metallurgist, Youngstown plant, Republic Steel Corp. These steels were required by construction of long-distance pipe lines for petroleum and natural gas lines.

The final paper was given by T. A. Thompson, asst. open hearth superintendent, Weirton Steel Co., on *Increased Open Hearth Production With the Use of Oxygen*. The author described a record heat of 585.9 tons made in 5 hr, 5 min. Careful preparation, special supervision, and use of large oxygen volumes made this possible. Production was 104 tons per hour on a tap-to-tap basis. Through the use of three roof lances, 898 cu ft of oxygen per ton of steel was consumed.

Chairmen of the technical session were A. T. Hubbard, superintendent, open hearths, Brier Hill works, Youngstown Sheet and Tube Co.; and K. F. Waggener, superintendent, Blooming mill, Youngstown plant, Republic Steel Corp. Officers of the Northern Ohio section responsible for organizing the meeting are the Chairman—E. J. Brandon, asst. div. superintendent, steel production U. S. Steel Corp., Youngstown; and the Secretary-Treasurer, F. J. Herman, superintendent bessemer dept., U. S. Steel Corp., Youngstown.

Mechanical Working Committee in Session

The Mechanical Working Committee of the Iron and Steel Division met in Pittsburgh at the Penn-Sheraton Hotel on April 29th. Members of the Committee worked on plans for the annual Technical Conference, to be held during January 1960. It is anticipated that the Conference will be of the symposium type, dealing with related subjects. Early formation of plans is being stressed by the Committee.

Journal of Metals Award Winners

A technical paper by two Japanese has been announced as winner of the JOURNAL OF METALS Award. The paper, *Making of Self-Fluxing Sinter and the Blast Furnace Practice with its 100 pct Sinter Burden*, was by Dr. Y. Doi, asst. manager, and K. Kasai, superintendent, blast furnaces, Sumitomo Metal Industries, Kokura Steel Works, Japan. The announcement was made at the Annual Fellowship dinner held by the 42nd conference of the National Open Hearth Committee and Blast Furnace, Coke Oven, and Raw Materials Committee, which met in St. Louis from April 6th to 8th.

Metallurgical Classic of Sixteenth Century Reissued in English

The *Pirotechnia of Vannoccio Biringuccio*, published in 1942 by the Mudd Fund of the AIME, has just been reissued by Basic Books Inc., New York, through the cooperation of The Metallurgical Society of AIME.

The original translation by Cyril Stanley Smith and Martha Teach Gnudi from the early Italian printings of this famous sixteenth century classic in metallurgy is presented in its entirety. The 1942 design by Carl Rollins is reproduced intact, along with the 84 illustrations that appeared in what was then the first English translation of the Biringuccio treatise. Dr. Smith has written a new foreword to the reissued work, as well as the introduction first composed by him for the 1942 edition.

The reissue of The Pirotechnia is part of Basic Books' "Collector's Series in Science." The classic is now generally available in this country

for the first time. The 1942 limited edition was almost immediately oversubscribed. Orders for the new boxed facsimile edition, priced at $8.50, may be sent direct to the publishers, *Basic Books Inc. 59 Fourth Avenue, New York 3, N. Y.*

Physical Metallurgists Tour AIRCO Labs During March Meeting

An interesting laboratory visit combined with a stimulating lecture resulted in another well-attended meeting of the Physical Metallurgy group of the New York section, AIME, on Tuesday, March 10th. More than 30 persons toured the research laboratories of the Air Reduction Co. Inc., in Murray Hill, N. J.

Following the tour the group reassembled at the Surburban Hotel, Summit, N. J., where they were joined by additional members who had been unable to attend the laboratory visit. An overflow crowd of more than 60 people heard Prof. Bruce Chalmers, of Harvard University, discuss *Grain Boundaries*.

Among the points visited during the tour of the AIRCO labs were the metallurgical, chemical, and welding laboratories, and the pilot plant section.

Of special interest to the visitors was AIRCO's adaptation of electron beam melting to welding, (presently in an early stage of development) a project concerning the perfect welding of thin stainless steel sheet, and a plasma jet torch capable of melting such refractory materials as zirconia and tungsten. (Electron beam melting and the plasma jet torch were described respectively in the February and January issues of JOURNAL OF METALS.) Fields of interest in the chemical laboratories extend into both organic and inorganic aspects, with the emphasis on the former. The group was told of projects dealing with paper and paper coatings, plastics, and paints, among others. The diversity of interests in the labs as a whole derives from AIRCO's role as an acetylene producer.

The speaker for the evening was introduced by John T. Eash, technical chairman. In a general review of *Grain Boundaries*, Prof. Chalmers reviewed the evolution of grain boundary theories in general. He showed how modern theories account rather well for low-angle boundaries, which are somewhat better understood than high-angle boundaries. Dr. Chalmers went on to describe the most recent experimental findings and the possible ways in which these might be interpreted. An extended period of questions and answers indicated a high level of interest in Dr. Chalmers' talk.

Arrangements for the meeting were handled jointly by Shadburne Marshall, of Air Reduction Co. Inc., and S. C. Carapella, Chairman of the New York Physical Metallurgy group.

Henry Krumb Honored By Board of Directors In Fund Name Change

"In December, 1938, a donor, whose identity was disclosed only to the Treasurer of the Institute (AIME), established a special fund which was designated Endowment Fund "X". In successive years, additional contributions were made. Under the terms of the gift, the income from this Fund may be used "for any purpose which is for the benefit of the Institute." While the donor states that the income of the Fund can be used to defray current expenses, he specifically expresses the wish that it be used preferably only in times of economic depression, so that the Institute will not be compelled to curtail its activities when income from other sources shrinks. Appropriations may be made by the Directors only upon recommendations of the Endowment Fund Committee,—such recommendations to be made at least two weeks in advance of the meeting of the Board of Directors at which appropriation is made. One objective of the donor of Endowment Fund "X", in addition to benefiting the Institute, was to show the soundness of investing in common stocks of well-operated mining and oil companies. His objective is well demonstrated by comparing the original principal with the market value of the Fund."

The author of this letter, which was addressed to Karl Eilers, then Treasurer of the AIME, was Henry Krumb, draftsman, engineer, assayer, chemist, and consulting mining engineer. Mr. Krumb died on Dec. 27, 1958 at the age of 83 (see JOURNAL OF METALS, March 1958, p. 204). One of the many tangible and intangible memories he left behind was *Endowment Fund "X"*. In 1938 he established the Fund, allowing his name to be known only to the Treasurer of the AIME.

Shortly before his death, Mr. Krumb removed the restriction that the name of the donor remain anonymous.

At the Board of Directors meeting of Feb. 15, 1959, President Augustus B. Kinzel said that the Fund had been increased from the original $96,212 to the present $860,272. C. R. Dodson, Treasurer of the AIME noted the three uses to which it had been put to date. The Directors voted that H. DeWitt Smith and Mr. Dodson be empowered to select the new name for the Fund. The name of *Endowment Fund "X"* was subsequently changed to *The Henry Krumb Memorial Fund* in honor of the man who gave 60 years to the mining profession and 53 years to the AIME.

HENRY KRUMB

Memorial Resolution Prepared By Henry DeWitt Smith

WHEREAS, with the death of Henry Krumb on December 27, 1958 this country has lost one of its most illustrious engineers, and the Institute one of its stoutest supporters, through adverse times and good, and

WHEREAS, during his fifty-three years of membership, he served as Vice President during the critical period from 1928 to 1942, and was awarded Honorary Membership in the Institute in 1939, and

WHEREAS, during his lifetime he concentrated as consulting mining engineer on the development of porhyry copper mines in the western United States and South America, combining engineering skill with financial acumen to the advantage of the copper industry of North and South America, and

WHEREAS he was an inspiration to his fellow engineers and an example to the younger generation in his professional conduct and modesty, and, through scholarships, encouraged them to become mining engineers;

THEREFORE, BE IT RESOLVED, that the American Institute of Mining, Metallurgical, and Petroleum Engineers record its great sorrow over the loss of this distinguished member of our profession, and

BE IT FURTHER RESOLVED, that this Resolution be spread upon the Minutes of this meeting, and a copy be sent to Mrs. Krumb.

February 15, 1959

IMPORTANT McGRAW-HILL BOOKS

METAL FATIGUE

By George Sines, University of California, Los Angeles; and J. L. Waisman, Douglas Aircraft Company. *McGraw-Hill UCLA Engineering Extension Series.* 415 pages, $12.50.

The most rational exposition of fatigue of metals to be found in one book. The editors have sought the leading authority for each subject and put the key information into print. Critically selected bibliographies are provided, and the introduction includes a guide to fatigue literature, for those not thoroughly familiar with the field. The book presents a coordinated advanced treatment, by men who are experts, writing on their own specialties. Much of the subject matter is new.

PHYSICAL METALLURGY

By C. Ernest Birchenall, Princeton University. 323 pages, $8.50

The science of metals has taken enormous strides in the past few decades. In this book, the author takes cognizance of the new concepts, theories and experiments in order to produce an elementary text that "reflects in some measure the progress of recent years, the ferment and vitality of the field at present." To provide a sound underlying framework, the book has a strong scientific approach, at the expense of the engineering aspects. This exposition of fundamentals help to emphasize the unity underlying all aspects of the subject. In this respect the book departs significantly from all the other physical metallurgy texts and represents the long-awaited and much-needed approach to the subject.

CONSTITUTION OF BINARY ALLOYS

By Max Hansen, Metallgesellschaft A. G., Frankfurt-Main, Germany; in cooperation with Kurt Anderko, Metallgesellschaft A. G., Frankfurt-Main, Germany. *McGraw-Hill Metallurgy and Metallurgical Engineering Series.* Second Edition. 1305 pages, $32.50.

This revision and translation of the German work provides a source of reliable data concerning the constitution of binary alloy systems (phase diagrams) and the crystal structure of metallic phases. Widely scattered information in the world's metallurgical, physical, chemical, and crystallographical literature is analyzed and critically evaluated. About 9600 literature references were considered and are included. Contains 684 diagrams and 1286 systems.

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Chicago Section NOHC Holds All-Day Meeting

The Chicago section of National Open Hearth Steel Committee held its annual all-day meeting on Wednesday, March 11th, with 220 registered for the technical sessions, and 270 for the dinner. The meeting was held at the Del Prado Hotel, Chicago.

Welcoming remarks were made by the Section Chairman, Harry W. Erler, asst. division superintendent, steel production, Gary works, U. S. Steel Corp., who then introduced R. W. Shearman, Secretary of the National Open Hearth Steel Committee. Appreciation was expressed for the gift of $500 to the Engineering Societies Building Fund from the Chicago NOHC section.

The Section award's first prize, a $100 bond, was won by R. N. Ames, general supervisor, ceramic development, and Arthur Sontz, ceramic engineer, development, South works, U. S. Steel Corp. for their paper, *Evaluation of Clinkered Dolomite Material*. In presenting the paper at the morning session, Mr. Sontz stated that for proper maintenance of bottoms and banks, clinkered dolomite is highly satisfactory because of its excellent refractory properties and ready availability.

A paper on *Experience in Use of Various Charge Oxides* was presented by M. E. Nickel, asst. superintendent, open hearths, Wisconsin Steel div., International Harvester Co. Co-author was E. T. Hickey, open hearth production and methods analyst. The authors established these criteria for a superior ore: high percentage of oxides to give high metal yields; in physical characteristics, hard, dense, and free of fines; minimum silica, acid, and moisture content. Low-silica charge ore proved best of those tried, giving the lowest average tap-to-tap time, and the greatest yield in tons per hour. A panel discussion followed on *Open Hearth Charge Oxides*. Participants were T. D. Hess, superintendent of No. 1 open hearth, Youngstown Sheet & Tube Co.; Howard Lee, practice foreman, No. 2 open hearth, Inland Steel Co.; and J. P. McCune, metallurgical investigator, development, Republic Steel Corp.

The last paper of the morning session, *Open Hearth Roof Repair With Fuel On*, was given by A. J. Voss, superintendent, masonry dept., Inland Steel Co. The author considered the effect of roof brick thickness on the rate of brick erosion.

On the afternoon session, the second prize, paper award, a $25 bond, was presented to K. V. Smith, chief development metallurgist, and D. V. Roloff, ceramic engineer, Gary works, U. S. Steel Corp. Mr. Smith presented their paper, *A Study of Hot Topping Practice*. In attempting to get greater efficiency from sinkheads, the authors experimented with different covering materials, and filling the hot top to varying volumes. After trying such materials as crushed brick, exothermic coverings, graphite, vermiculite, and even corncobs, a box cover at 14 pct volume was found to give the best sinkhead characteristics. The authors also pointed out the importance of adequate time for ingots to solidify before hot tops are removed—determined to be 90 min. On the subject of *Hot Topping Practice*, a second paper was given on the *Use of Insulated Hot Top Covers*, by J. W. Owens, metallurgist, Wisconsin Steel div. International Harvester Co. By selection of the proper covering material, depth of pipe can be reduced. The author was able to obtain one additional ingot per heat, and increase yield by 3.1 pct.

Receiving honorable mention for their paper on *A Study of the Influence of Bath Deoxidation on the Cleanliness of 1030 Steel* were K. R. Mattson, asst. superintendent, metallurgy dept., and R. W. Joseph, asst. supervising metallurgist, Inland Steel Co. In presenting the paper, Mr. Mattson compared "regular practice" of adding part of the deoxidizer in the ladle to the "modified practice" of putting all the ferromanganese in the ladle. The result of "modified practice" was to obtain 15 pct better manganese efficiency, better control of the manganese, and a reduced heat time of 15 min.

A Program for the Control of Open Hearth Chemistry was described by T. D. Hess. The paper was co-authored by R. L. Kimberly; it will be reviewed in the June issue of JOURNAL OF METALS.

A panel discussion on *Operating Metallurgy* followed. Participants were M. E. Goetz, J. F. Tucker, superintendent, No. 1 open hearth, Gary works, U. S. Steel Corp; L. I. Dumpert, asst. superintendent, No. 2 open hearth; and William Hoff, metallurgy dept., Republic Steel Corp.

The afternoon session was concluded with a paper on pit practice, *Survey of Moulds and Stools*, by E. R. Rosenow, chief specifications metallurgist, South works, U. S. Steel Corp. Factors affecting mould life, such as iron chemistry and foundry practice, were studied. It is realized that high consumption rate of moulds and stools is a matter of continued consideration.

The meeting was concluded with a cocktail hour and dinner, at which Harry W. Erler presided. Participating in the program planning were the Vice Chairman, M. E. Nickel; the Secretary-Treasurer, A. M. Kroner, asst. superintendent, No. 3 open hearth, Inland Steel Co.; and the Chairman of the Suppliers' committee, Paul Haserodt, E. J. Lavino & Co. New Section officers were announced: Chairman—M. E. Nickel; Vice Chairman—A. M. Kroner, Secretary-Treasurer—Rex McLain, superintendent, steel production, South works, U. S. Steel Corp.

AIME

BOARD OF DIRECTORS

Recent actions taken by the Institute Board of Directors.

By action of the AIME Board of Directors at its meeting on Feb. 15, 1959, effective in 1960, the Institute has increased the per member rebate to local sections from $0.50 to $0.75 and, in lieu of travel expenses for delegates, has increased the minimum to local sections from $100 to $250, with a maximum of $600 per section.

Each section may decide whether to select a delegate whose company will pay his travel expenses to the Annual Meeting, as happens with most of the 2500 members attending such meetings, or pay the travel expenses out of the section funds. It is anticipated that a section may select the best delegate possible and, in most cases, have the funds previously allotted by the Institute for travel expenses available for other section activities.

The Executive Committee of the Extractive Metallurgy Div. adopted the following amendment to its by-laws on Feb. 17, 1959, in order to provide for the proper functioning of its Publications Committee:

Article IX, Section 4:

"The duties of the Publication Committee shall be to examine and review all papers in its field submitted to the Society for publication; to evaluate reader comment obtained on each paper; and to recommend to the Publications Committee of The Metallurgical Society as to acceptance or rejection of papers for TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME. It also may assist the Editor of JOURNAL OF METALS on the acceptance of papers in its field for publication.

EJC Activities

The Engineers Joint Council has accepted with regret the resignation of William T. Cavanaugh, executive secretary of the Engineering Manpower Commission. Mr. L. K. Wheelock, assistant secretary of EJC, will replace Mr. Cavanaugh.

At the annual board of directors meeting in January, a seven point recommendation for strengthening and implementing the work of EJC was made. A proposal was approved by the Council for the steps to be taken toward eventual merging of EJC, ECPD, and EMC under one corporation, with each division maintaining its own identity.

AROUND THE SECTIONS

Boston section held its 7th meeting at the Massachusetts Institute of Technology Faculty Club on April 6th. The meeting was the annual Richards' Night, in memory of Professor Richards. The speaker, a member of E. I. DuPont de Nemours Company's explosive dept., discussed the problems of designing large scale blasts and presented a film prepared by DuPont of Canada on the blasting of Ripple Rock.

Chicago section held its annual ladies night on March 4th. The 59 members and guests heard Eldred E. Green, consulting horticulturist, talk on *Landscaping with Flowers, Shrubs, and Trees.* Technical chairman for the session was Dr. Paul Gordon.

Florida section has scheduled a field trip to the Cape Canaveral Missile Base on June 5th. Prepared as an alternate is a visit to Tampa industries: Florida Steel Corp. Rolling Mills, lunch at the Columbia Restaurant, followed by a visit to the General Cable Co.

San Francisco section held its monthly meeting at The Engineers Club on March 11th. Guest speaker was Pete Fowler, Kaiser Engineers Overseas Corp. Mr. Fowler pointed out *General Conditions in India Affecting Exploration and Development in The Mineral Industries.*

Cleveland section gathered for cocktails and dinner on March 19th. Technical Chairman Emil Perout presented as guest speaker Dr. Richard J. Lund, who is presently serving as the assistant technical director of Battelle Memorial Institute. Dr. Lund discussed *Meeting and Creating Future Demands for Uncommon Metals—A Challenge.*

University of Utah Student Chapter, AIME, and the Student Affairs committee of the Utah section were hosts to the Section officers and executive committee at a smorgasbord dinner on March 6th. The dinner was an informal *get-acquainted* affair, presided over by Student Chapter President Richard Knostman. Highlight of the evening was a general discussion directed at encouraging students to join student chapters and to participate in the yearly student paper competition.

PERSONALS

T. B. Massalski has joined the Mellon Institute as a Senior Fellow in the Metal Physics fundamental research group. Dr. Massalski has published some 15 papers in his field, and has been a postdoctoral fellow at the Institute of Metals, University of Chicago, a consultant to the Max Planck Institute for Metals Research, Germany, and a consultant and lecturer at Battelle Memorial Institute. Prior to this appointment, Dr. Massalski lectured in physical metallurgy at the University of Birmingham, England.

Robert E. Keith has been appointed to the staff of liaison scientists, at the General Electric Research Laboratory, Schenectady,N. Y. Dr. Keith has been a metallurgist on the staff of General Electric since 1954. In 1958, he helped organize the Hudson-Mohawk section of The AIME, and is presently the Section's first chairman.

Neil Plummer has been named as superintendent of the Arthur Milling dept., Kennecott Copper Corp., Utah Copper div. He was formerly mills metallurgical engineer. **J. W. Ribotto** succeeds Neil Plummer as mills metallurgical engineer with Kennecott Copper Corp. He was formerly superintendent of the mills service dept.

Frederick G. Jaicks has been appointed general manager of the Inland Steel's Indiana Harbor works, East Chicago.

M. D. Hassialis, head of Columbia University School of Mines, has been elected president of Pacific Uranium Mines Co. Dr. Hassialis is an international authority in mineral engineering and uranium processing.

Robert C. Hills has taken the president's chair at Freeport Nickel Co., N. Y. He is an executive vice president of the parent firm, Freeport Sulphur Co.

Floyd R. Anderson former administrative assistant, has been named chief metallurgist of the Denver div., Gardner-Denver Co., Quincy, Ill.

Thor N. Rhodin, associate professor of engineering physics at Cornell University, has been named a member of the metallurgical engineering department. He will conduct a graduate seminar in the physical chemistry of metals.

William J. Phillips has resigned as vice president of the Crawford Steel Foundry Co., Bucyrus, Ohio.

Alexander Squire has been appointed manager of the newly formed Materials dept. of the Bettis Atomic Power division, Westinghouse Electric Corp.

Arthur B. Backensto, Jr. was named research metallurgist of the Alan Wood Steel Co. In his new post, Dr. Backensto will head a research program directed toward the increased use of iron powder.

S. F. Reiter has been named a lecturer in the Dept. of Metallurgy at Yale University. He is giving a course in metals technology.

Richard B. Shaw, general superintendent of melting operations at the Brackenridge works of the Allegheny Ludlum Steel Corp., has been awarded the *Allegheny Ludlum Award and President's Medal* in recognition of "his outstanding contribution to the development of low-cost, high quality silicon and stainless steel melting."

Sidney Siegel, formerly manager of engineering, M. & C. Nuclear Inc., is now executive vice president of the U. N. Alloy Steel Corp., Boston.

Change of address: **Robert C. Williams,** formerly with Battelle Memorial Institute, to Columbiana Foundry Co., Columbiana, Ohio.

Stanley Abkowitz has been named supervisor of new alloy development in the special metals field, as well as process development and melting services at Mallory-Sharon Metals Corp.

Lee S. Busch now heads the new Mallory-Sharon research and development team interested in special metals. Mr. Busch is technical director of the company.

C. Dale Dickinson has been handed the responsibility of developing new knowledge of the metallurgy of titanium, zirconium, and other special metals at Mallory-Sharon. He will establish fundamental metallurgical principles relating to these metals and their chemical, mechanical, and physical properties.

Richard W. Fountain has accepted an appointment as technical supervisor in the metals research group of the technology department of Union Carbide Metals Co. Dr. Fountain's responsibilities include the execution of certain research programs and coordination of activities with the laboratory.

NECROLOGY

Date Elected	Name	Date of Death
1940	Babin, C. L.	Unknown
1949	Bauer, G. Gerald	Unknown
1947	Boyd, Eric E. G.	May 9, 1958
1898	Buck, Victor B. (Legion of Honor)	Unknown
1952	Carter, P. Thos.	Unknown
1948	Chomiak, Ben B.	1958
1949	Coda, Agostino G.	Nov. 21, 1958
1956	Cuneo, James M.	Jan. 28, 1959
1940	Eggers, John H.	Jan. 9, 1959
1913	Elsing, M. J.	Feb. 27, 1959
1939	Gray, E. Gordon	Unknown
1903	Greenidge, S. M. (Legion of Honor)	Jan. 2, 1959
1928	Holter, Norman B.	Feb. 8, 1957
1956	Jackson, F. M.	Dec. 11, 1958
1917	Knox, John	Unknown
1946	Kunze, Keith	Dec. 29, 1958
1941	Leavenworth, P. B.	Dec. 31, 1958
1936	McIlvain, Jr., R. W.	Feb. 16, 1959
1925	Moore, James E.	Dec. 7, 1958
1951	Nichols, N. W.	Unknown
1925	Norden, Joseph A.	Jan. 7, 1959
1918	Olson, Louis W.	December 1958
1946	Pryor, E. K.	June 1, 1958
1952	Randall, Donald H.	Feb. 22, 1959
1943	Sheedy, John W.	Jan. 16, 1959
1917	Shoffstall, A. S.	Feb. 23, 1959
1957	Swingle, Harold R.	Jan. 31, 1959
1902	Utley, Howard H. (Legion of Honor)	Feb. 15, 1959
1953	Ward, E. Stuart	Feb. 27, 1958
1954	Watters, W. H.	Dec. 6, 1958
1914	Wise, Sidney L.	Feb. 28, 1959

OBITUARIES

Victor B. Buck (associate member 1898), date of death unknown. Mr. Buck attended Columbia University at the turn of the century. His last address was in New York City.

Percival T. Carter (member 1952) died on an unknown date as the result of a climbing accident. Dr. Carter was a member of the metallurgy department at The Royal College of Science & Technology, Glasgow, Scotland.

James M. Cuneo (junior member 1957) died on Jan. 28, 1959. Mr. Cuneo was a recent graduate of the University of Michigan and a native of Dover, Ohio.

Louis W. Olson (member 1918) passed away in December 1958. Mr. Olson received his education at the University of Wisconsin and was associated with The Ohio Brass Co. since 1902.

Edward K. Pryor (member 1946) died on June 1, 1958. Mr. Pryor was a member of Battelle Memorial Institute research staff, later moving to Whittier, Calif., as president of the Pryor-Giggey Co. He held an M.S. in metallurgy from the University of Arizona.

Arthur S. Shoffstall (member 1917) suffered a stroke on Jan. 1, 1959 and passed away on February 23rd. Mr. Shoffstall held an M.S. from The Pennsylvania State College, School of Natural Science. He was associated for many years with The International Nickel Co.

McKune Award Winner Announced in April

The Metallurgical Society of the AIME recently announced that its McKune Award has been won by G. M. Hagenberger, Standard Steel works div., Baldwin-Lima-Hamilton Corp., Burnham, Pa.

The F. B. McKune Memorial Award, established by the Open Hearth Steel Committee of the ISD, is for an outstanding technical paper by an author under 40 years of age. Mr. Hagenberger's subject was *Conversion of 70 pct Natural Gas Utilizing a Continuous Oxygen and Combustion Analyzer.*

Announcement of the winning paper was made at a general session of the 42nd conference, National Open Hearth Steel Committee, and Blast Furnace, Coke Oven, and Raw Materials Committee which met in St. Louis from April 6th to 8th.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Feb. 28, 1959 was 30,889; in addition 3,974 Student members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Brytczuk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

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Clay, Donald H., Birmingham.
Given, James, Rockwood, Tenn.
Glunt, James A., Conshohocken, Pa.
Goldberg, Alfred, Monterey, Calif.
Hains, Donald J., York, Pa.
Harris, Thomas H., Birmingham.
Henrie, Thomas A., Boulder City, Nev.
Highberger, Grant H., Cleveland.
Hill, Jack R., Pittsburgh.
Himmel, Lawrence, Washington, D.C.
Hoch, Michael, Cincinnati.
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Johnson, Donald F., Hammond, Ind.
Kramlick, Emil S., Anaconda, Mont.
Leech, Robert C., Schenectady.
Leonelli, Bruno, Highland Park, Mich.
Li, Chou H., Newark.
Losinski, Stanley J., Gary.
Lowey, John R., Cleveland.
Meyer, Robert A., Setauket, N.Y.
Miller, Keith L., Portland, Ore.
Morgan, David W., Permanente, Calif.
Mortimer, George D., Medford, Mass.
Moss, David W., Lake Park, Fla.
Nenno, Soji, Osaka, Japan.
Oss, Frank E., Livonia, Mich.
Rudolf, John J., Munster, Ind.
Russel, Robert G., Whittier, Calif.
Salomonson, Fritz A., Anaconda, Mont.
Schwartz, Werner H., Frankfurt/M-Neiderursel, Germany.
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Such, Louis H., Natrona Heights, Pa.
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Wagner, James B., Jr., New Haven.
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Coming Events

May 4, AIME, NOHC Chicago Local Section, Spring meeting at Phil Smidt's Restaurant, Hammond, Ind.

May 6, AIME, New York Section, joint meeting of Physical metallurgists and powder metallurgists. Laboratory tour followed by dinner-meeting, Stevens Institute of Technology, Hoboken, N. J.

May 14, AIME, NOHC Cleveland Section, meeting, Rockside Gardens, Cleveland. Topic: Basic Roofs.

May 21-22, AIME New England Regional Conference, Statler Hotel, Hartford, Conn.

June 5, AIME, NOHC Southern Ohio Section. Golf Outing, Summit Hills Country Club, Fort Mitchell, Kenton County, Ky.

June 10, AIME, NOHC Northern Ohio Section, annual golf party at the Squaw Creek Country Club, Youngstown, Ohio.

June 15, AIME, NOHC Pittsburgh Section, Golf Party, Churchill Valley Country Club.

June 15, AIME, NOHC Eastern Section, plant visit to E. J. Lavino & Co. and G. & W. H. Corson Inc.; golf party at Plymouth Country Club, Plymouth Meeting, Pa.

June 20, AIME, NOHC Cleveland Section, Dinner-Dance, Lake Shore Hotel, Cleveland.

Aug. 23-25, Conference on the Fracture of Engineering Materials (ASM), Rensselaer Polytechnic Institute, Troy, N.Y.

Aug. 31-Sept. 2, Semiconductors Conference, Statler Hotel, Boston, Mass.

Oct. 7-9, Sixth National Symposium on Vacuum Technology of the American Vacuum Society, Sheraton Hotel, Philadelphia.

Oct. 16-17, AIME, NOHC Southern Ohio Section, Fall Meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Nov. 2-6, Fall Meeting of The Metallurgical Society of AIME, Morrison Hotel, Chicago.

Nov. 6, AIME, NOHC Pittsburgh Section, Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 16-20, Conference on Magnetism and Magnetic Materials, Sheraton Hotel, Philadelphia.

Dec. 2-4, AIME 17th Electric Furnace Steel Conference, Hotel Cleveland, Cleveland, Ohio.

Feb. 14-18, 1960, AIME Annual Meeting, Hotel McAlpin and Hotel Statler, New York.

Apr. 4-6, 1960, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

June 13-15, 1960, first International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPI.

Sept. 27-30, 1960, AIME Cleveland Section, Iron and Steel Exposition of Assn. of Iron and Steel Engineers, Public Auditorium, Cleveland.

Oct. 17-21, 1960, Fall Meeting of The Metallurgical Society of AIME, Sheraton Hotel, Philadelphia.

Nov. 4, 1960, Pittsburgh Section, NOHC, Off-the-Record Meeting.

Nov. 30-Dec. 2, 1960, 18th Electric Furnace Steel Conference, Morrison Hotel, Chicago.

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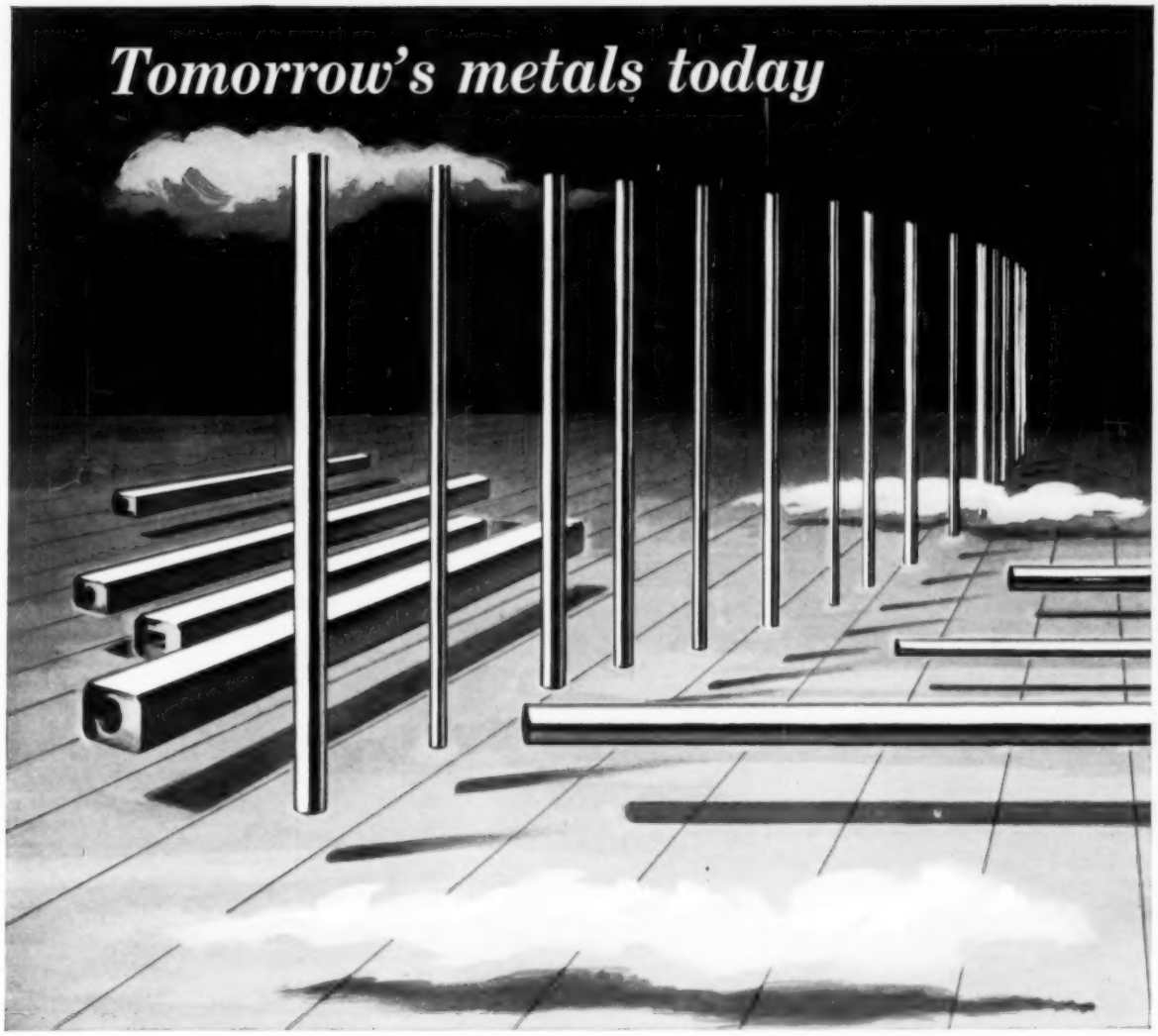

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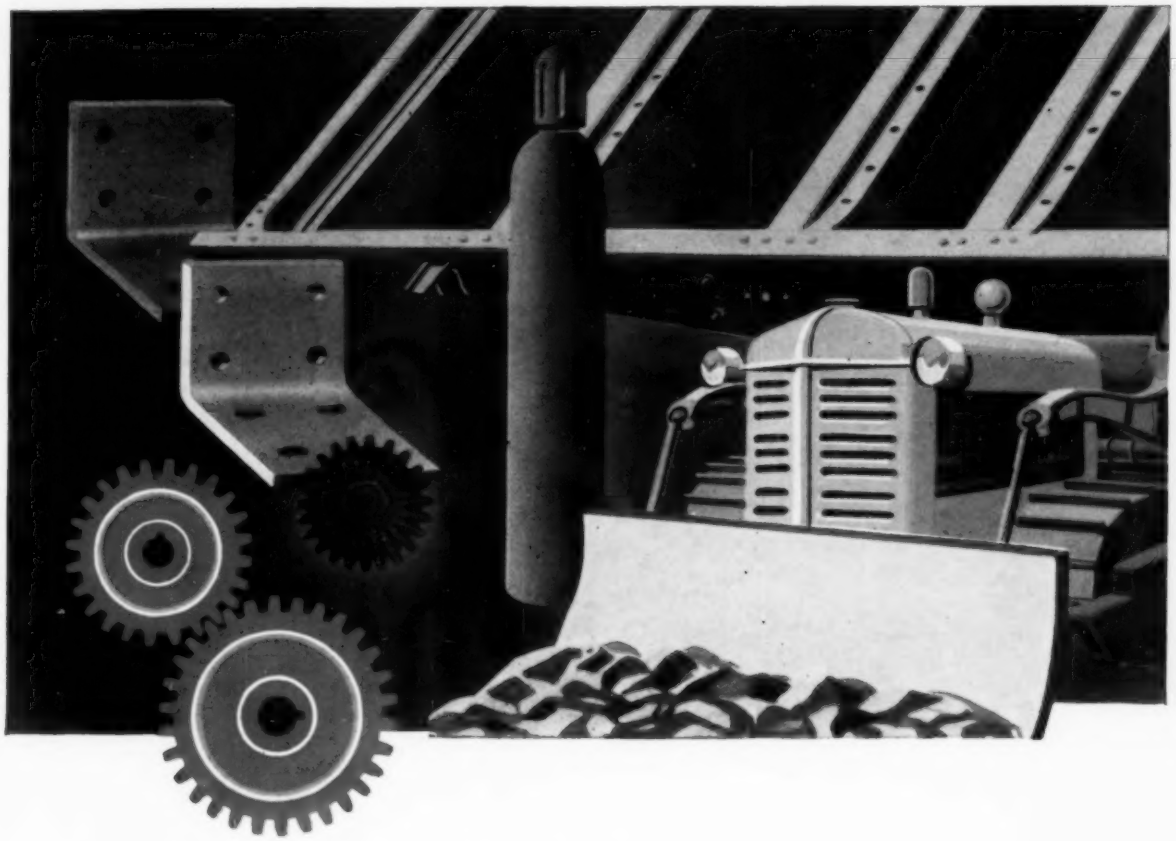

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